GRIGORE T. POPA UNIVERSITY OF MEDICINE AND PHARMACY IASI

HABILITATION THESIS

Interdisciplinary insights in stomatognathic system functional balance

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CONTENTS

ABBREVIATIONS

ACR – American College of Rheumatology
AFM – Atomic Force Microscopy
AI – artificial intelligence
BOP – Bleeding on probing
CAL – clinical attachment level
CBCT – Cone Beam Computed Tomography
CBCT – Cone Beam Tomography
CBL - Case-Based Learning
CRP – C-reactive protein
DAS28 – Disease Activity Score on 28 joints
DSSS – Dysfunctional Syndrome of the Stomatognathic System
EDSX – Energy-Dispersive X-ray Spectroscopy
ESEM – Environmental Scanning Electron Microscopy
EULAR – European League Against Rheumatism
EUSTAR – European Scleroderma Trails and Research Group
FEA – Finite Element Analysis
FRC – Fiber-Reinforced Composite
FRC-P – Polyethylene Fiber-Reinforced Composite
FRC-S – Glass Fiber-Reinforced Composite
GI – Gingival Index
GR – Gingival Recession
IL – Interleukin
IRD – Inflammatory Rheumatic Disorders
MD – tooth mobility
PBL - Problem-Based Learning
PD – Pocket Depth
PDL – Periodontal Ligament
PEEK - Polyether Ether Ketone
PI – Plaque Index
PPD – Probing Pocket Depth
RA – Rheumatoid arthritis
RF – Rheumatoid Factor
SEM – Scanning Electron Microscope
SPM – Scanning Probe Microscopy
SPT - Periodontal Support Therapy
SRC – Metal Wire AND Composite
SSc – Systemic Sclerosis
TCZ – Tocilizumab
TER - Resistive Electro-Tensometric Transducer
TMJ – Temporomandibular Joint
TNF – Tumor Necrosis Factor
XFEM – Extended Finite Element Method

THESIS SUMMARY

Our profession offers us the privilege and the challenge to activate in 3 main directions: education, health and research. Each of these domains requires a distinct, continuous training to cope with the specific and constantly increasing requirements. Under these circumstances, a solid, successful career involves maintaining standards and achieving performance that equally targets all three directions.

The habilitation thesis entitled "Interdisciplinary insights in stomatognathic system functional balance" reflects my contributions in the three mentioned fields for the last 15 years of my career, after the completion of PhD thesis.

Based on the recommendations of the National Council for Attestation of University Degrees, Diplomas and Certificates (CNATDCU) and on the order of the Ministry of Education and Scientific Research no. 3121/2015, the thesis is structured in three major sections:

- **Section I** – maps my professional, academic and scientific achievements
- **Section II** – presents future development plans regarding teaching career and research activity
- **Section III** – includes the references to support the presented research.

Section I is structured in two parts. One part is dedicated to the overview of my accomplishments in the medical professional activity, in the teaching one and in the scientific research. The other part encompasses the scientific achievements of the postdoctoral period, presenting the synthesis of three of my main postdoctoral scientific research directions:

1. ***Cumulative factors involved in maintaining or restoring the balance of stomatognathic system***

The stomatognathic system is an adaptative system which is constantly subjected not only to environmental factors but also to supra- and sub-systemic factors, struggling for maintaining a good balance between risk factors and host factors. The correct identification and quantification of any factor impairing on this equilibrium is mandatory for choosing the correct therapeutical strategy. The fixed dental prothesis are meant to restore the integrity of the dental arch but also to restore the homeostasis of the stomatognathic system. The moment we choose to implement it is strictly related to the good or improved status of all the other systems and subsystems of the body. Therefore, the prosthodontist has to integrate the information related to all the components of stomatognathic system – teeth, periodontium, oral mucosa, maxillary bones, TMJ, muscles and even to general condition. This is why my research has also an interdisciplinary aspect, focused on the local, loco-regional and general factors that can interfere with the balance of the stomatognathic system.

2. ***Research on the biomechanics of dental restorations***

The success of a dental restoration depends on reaching an equilibrium between the live natural structures and the artificial substitutes that come to fill in the substance defect. The biological and functional integration of these restorations becomes fundamental in the context of a wide diversity of clinical scenarios. In relation to these scenarios, numerous therapy options exist, and both, the talent and the competence of the practitioner, are measured quite often by his/her ability to find the correct therapeutic solution, perhaps even more than by the impeccable implementation of this solution. Biomechanical problems arise in the case of all dental restorations, regardless of their type, but particularly in the case of indirect ones, when it is necessary to highlight the biomechanical stresses to which each component is subjected: the restorations, the dental tissues on which the restorations are applied on and the supporting periodontal tissues.

3. Software for medical dental practice and education

Information technology penetrates various fields of activity, medicine being one of the most privileged. What is particular for medicine is its human dimension that can't be substituted by a computer. However, there are some activities in which the computer can take over some of the duties or can assist the practitioner during the medical act itself or auxiliary activities.

This chapter presents in its first part, some of our original software applications regarding administration, management and electronic archives of patients' documentation, radiographic imagine processing, and analysis and interpretation of clinical situation contributing to the decision-making process. The second part is focused on one of the most modern and efficient computer-assisted learning methods, the virtual patient concept, getting an overview picture of the most popular virtual patient software currently available, and presenting some examples of virtual patients authored with OpenLabyrinth, an open-source software.

Section II is dedicated to future research and academic projects that I intend to develop. For the future I intend to focus on each of the three main pillars of my career – medical profession, teaching and scientific research. The future research directions encompass:

- Research in the field of fixed prosthetic restorations with focus on biomechanical behavior
- Factors involved in homeostasis and dishomeostasis of stomatognathic system
- Information technology in dental medicine

Section III presents a list of bibliographic references that support the methodology, the results and the international context of knowledge for the research topics addressed.

REZUMATUL TEZEI

Profesia noastră ne oferă privilegiul și provocarea de a activa în 3 direcții principale: educație, sănătate și cercetare. Fiecare dintre aceste domenii necesită o pregătire distinctă, continuă pentru a face față cerințelor specifice și în continuă creștere. În aceste condiții, o carieră solidă, de succes, presupune menținerea standardelor și atingerea performanței care vizează în mod egal toate cele trei direcții.

Teza de abilitare intitulată „Perspective interdisciplinare în echilibrul funcțional al sistemului stomatognatic" reflectă contribuțiile mele în cele trei domenii menționate în ultimii 15 ani ai carierei mele, după finalizarea tezei de doctorat.

În baza recomandărilor Consiliului Național de Atestare a Titlurilor, Diplomelor și Certificatelor Universitare (CNATDCU) și a ordinului Ministerului Educației și Cercetării Științifice nr. 3121/2015, teza este structurată în trei mari secțiuni:

- **Secțiunea I** – trece în revistă realizările profesionale, academice și științifice;
- **Secțiunea a II-a** – prezintă planurile de dezvoltare viitoare privind cariera didactică și activitatea de cercetare
- **Secțiunea a III-a** – include referințele bibliografice ce susțin cercetarea prezentată.

Secțiunea I este structurată în două părți. O parte este dedicată trecerii în revistă a realizărilor personale în activitatea profesională medicală, în cea didactică și în cercetarea științifică. A doua parte cuprinde realizările științifice ale perioadei postdoctorale, prezentând sinteza a trei dintre principalele mele direcții de cercetare științifică postdoctorală:

1. Factori cumulativi implicați în menținerea sau restabilirea echilibrului sistemului stomatognat

Sistemul stomatognat este un sistem adaptativ care este supus constant nu numai factorilor de mediu, ci și factorilor supra- și subsistemici, luptând pentru menținerea unui echilibru corect între factorii de risc și factorii gazdă. Identificarea și cuantificarea corectă a oricărui factor care afectează acest echilibru este obligatorie pentru alegerea strategiei terapeutice corecte. Protezele dentare fixe au menirea de a restabili integritatea arcadei dentare, dar și de a restabili homeostazia sistemului stomatognat. Momentul în care alegem să implementăm o soluție este strict legat de starea tuturor celorlalte sisteme și subsisteme ale corpului. Prin urmare, medicul protetician trebuie să integreze informațiile referitoare la toate componentele sistemului stomatognat – dinți, parodonțiu, mucoasa bucală, oasele maxilare, ATM, mușchi și chiar starea generală. Iată de ce cercetarea mea are caracter interdisciplinar, axat pe factorii locali, loco-regionali și generali care pot interfera cu echilibrul sistemului stomatognat.

2. Cercetări privind biomecanica restaurărilor dentare

Succesul unei restaurări dentare depinde de atingerea unui echilibru între structurile naturale vii și înlocuitorii artificiali care vin să completeze defectul de substanță. Integrarea biologică și funcțională a acestor restaurări devine fundamentală în contextul unei largi diversități de scenarii clinice. În raport cu aceste scenarii, există numeroase opțiuni terapeutice și atât talentul cât și competența practicianului sunt testate destul de des, capacitatea acestuia de a găsi soluția terapeutică corectă putând deveni poate chiar mai importantă decât implementarea impecabilă a acestei soluții. Problemele biomecanice apar în cazul tuturor restaurărilor dentare, indiferent de tipul lor, dar mai ales în cazul celor indirecte, când este necesar să se țină cont de solicitările biomecanice la care este supusă fiecare componentă: restaurările, țesuturile dentare pe care acestea se aplică și țesuturile parodontale de susținere.

3. Software pentru practica și educația medicală stomatologică

Tehnologia informației pătrunde în diverse domenii de activitate, medicina fiind una dintre cele mai privilegiate. Ceea ce este particular pentru medicină este dimensiunea sa umană, care nu poate fi înlocuită de un computer. Există însă unele activități în care computerul poate prelua o serie de atribuții sau poate asista medicul în timpul actului medical propriu-zis sau al activităților auxiliare.

Acest capitol prezintă, în prima parte, câteva dintre aplicațiile noastre software originale privind administrarea, gestionarea și arhivarea electronică a documentelor pacienților, prelucrarea imaginilor radiografice și analiza și interpretarea situației clinice ca parte a procesului decizional. A doua parte este concentrată pe una dintre cele mai moderne și eficiente metode de învățare asistată de computer, conceptul de pacient virtual, pe imaginea de ansamblu a celor mai populare software pentru pacient virtual disponibile în prezent și pe prezentarea a câtorva exemple de pacienți virtuali creați cu OpenLabyrinth, un software cu sursă deschisă.

Secțiunea a II-a este dedicată viitoarelor proiecte de cercetare și academice pe care intenționez să le dezvolt. Pentru viitor intenționez să mă concentrez pe fiecare dintre cei trei piloni principali ai carierei mele – profesia medicală, predarea și cercetarea științifică. Direcțiile viitoare de cercetare cuprind:

- Cercetări în domeniul restaurărilor protetice fixe cu accent pe comportamentul biomecanic
- Factori implicați în homeostazia și dishomeostazia sistemului stomatognat
- Tehnologia informației în medicina dentară

Secțiunea a III-a prezintă o listă de referințe bibliografice care susțin metodologia, rezultatele și nivelul internațional de cunoaștere pentru temele de cercetare abordate.

SECTION I. PROFESSIONAL, ACADEMIC AND SCIENTIFIC ACHIEVEMENTS

1. OVERVIEW OF PROFESSIONAL, ACADEMIC AND SCIENTIFIC ACHIEVEMENTS

Our profession offers us the privilege and the challenge to activate in 3 main directions: education, health and research. Each of these domains requires a distinct, continuous training to cope with the specific and constantly increasing requirements. Under these circumstances, a solid, successful career, involves maintaining standards and achieving performance that equally targets all three directions.

The academic environment, as the highest expression of social responsibility, requires the exercise of behavioral skills in the spirit of a civilized and constructive dialogue, collaboration and mutual trust. Integrity, transparency, compliance, proactivity, honesty and respect - principles set out in the Code of Ethics agreed by the signatories of the National Pact of Integrity for the Academic Environment [1] - must be the basis of our activities, underlying our mission to cultivate students' passion for the chosen profession and to mark their professional existence in a positively memorable way. The same principles contribute to establishing a professional work environment, meant to create, for our patients, the mental and emotional comfort necessary to carry out correct dental therapeutic acts and to ensure the ethical framework for carrying out research activities. In more than 20 years since I have been active in our university, I have had the privilege of having the support and the framework in which to develop my personal and professional abilities, in the spirit of the above stated principles.

1.1. PROFESSIONAL PROGRESS

The landmarks of my professional evolution are intrinsically related to the high school and university studies I graduated, that nurtured my curiosity and interest in the medical field.

Being engaged in the field of prosthodontics, I was certified as Senior specialist in General Dentistry and later, when the new specialty of Prosthodontics was established, I was certified also in this specialty.

1992	**High-school diploma,** no. 25/13.VIII.1992, Mathematics-physics profile "Emil Racoviţă" High School, Iaşi
1998	**Doctor - dentist,** Bachelor's degree no. 419 / 22.XII.1998 Faculty of Dentistry, University of Medicine and Pharmacy “Grigore T. Popa”, Iași
1999	**Trainee in General Dentistry -** University Dental Polyclinic University Clinical Hospital "Saint Spiridon" Iasi
2000	**Specialist in General Dentistry,** confirmed by the Order of the Minister of Health no. 191/2000
2008	**Senior specialist in General Dentistry** confirmed by the Order of the Minister of Health no. 1971/03.12.2008

2013	**Certificate of complementary studies in Implantology**, confirmed by Order of the Minister of Health no. 34221/30.05.2013
2014	**Specialist in Prosthodontics**, confirmed by Order M.H. no. 575/21.05.2014

We have the opportunity to work in an area which is constantly subject to change, challenges and, in addition, to demands and under the scrutiny of our students and patients. The desire for improvement comes naturally and is a process that needs to be carried out continuously, self-limitation being a trap that we are, fortunately, forced to avoid. Even if prosthodontics is generally regarded as invasive therapy, I'm a constant advocate of minimal invasive restorations, by using new improved materials and technologies allowing minimal reduction of dental tissues.

Beyond the constant interest for improvement in the field of dentistry, reflected in constant participation in national and international scientific events and post-graduate courses, my interests also include computer science, project management and training:

- Certificate "*Research project management*" within the project "Project management for competitive research", CEEX 2005, project director Prof. Dr. Oprea D., "Al. I. Cuza" University Iaşi, 9.10 – 10.12.2006
- Postgraduate course "*Methodology of research and elaboration of scientific papers*" - coordinators Prof. Dr. Căruntu I., Prof. Dr. Azoicăi D., "Grigore T. Popa" U.M.Ph. Iasi, 2010
- Certificate of participation - "*Program for improving IT skills in the use of the Management Campus Dashboard Solution*", within POSDRU/86/1.2/62594, 22.05 – 25.05.2012
- Certificate "*Trainer of trainers*" - COR 241205 - AFS study training association, Iasi, Romania, 2012
- Certificate of completion of the training course "*Project Manager*", no. 1153/24.07.2014, 23 - 26.06.2014, Iași
- PC operating knowledge:
    - Windows 10 operating system
    - Microsoft Office applications (MS Word, Excel, Power Point)
    - Image processing (Corel Photo-Paint, Adobe Photoshop)
    - Statistical processing (Statistica, SPSS, Epi Info)
    - 2D graphics (Xara X, Xara Designer Pro, Corel Draw)
    - 3D graphics (Rhinoceros, Solidworks)
    - FEA (Cosmos DesignStar, ANSYS Workbench)

My interest in 3D modelling and finite element analysis (FEA) was materialized in multiple scientific papers and collaborations in doctoral studies along the years.

1.2. ACADEMIC ACTIVITY

After the end of the internship year, in 1999 I passed the exam for *junior assistant*, starting my teaching career at the Faculty of Stomatology Iasi in 2000, within the Department of Prosthodontics, led by Prof. Dr. Vasile Burlui.

The timeline of my academic evolution is the following:

01.01.2000	**Junior Assistant –** Discipline of Gnatoprosthetic, Faculty of Dental Medicine, "Grigore T. Popa" U.M.Ph. Iași
24.02.2003	**Assistant** – Discipline of Fixed Prosthodontics, Faculty of Dental Medicine, "Grigore T. Popa" U.M.Ph. Iași
18.02.2013	**Lecturer** – Discipline of Fixed Prosthodontics, Gnathology, Dento-Somato-Facial

	Esthetics, Department of Odontology – Periodontology, Fixed Prosthodontics, Faculty of Dental Medicine, “Grigore T. Popa” U.M.Ph. Iași
03.10.2016	**Assoc. Prof. -** Discipline of Fixed Prosthodontics, Gnathology, Dento-Somato-Facial Esthetics, Department of Odontology – Periodontology, Fixed Prosthodontics, Faculty of Dental Medicine, “Grigore T. Popa” U.M.Ph. Iași
2005 - present	**PhD Doctor in Dental Medicine –** confirmed by the Order of the Minister of Education and Research no. 3956/25.04.2005; thesis “Clinical-technological study on the dento-prosthetic joint in ceramic restorations”, scientific coordinator Prof. Dr. Vasile Burlui

During the first years, my academic activity was mainly focused on three directions: (a) teaching our students the practical skills needed for their future medical practice, (b) contributing to writing of some specialty books under coordination of Prof. Dr. Vasile Burlui and Prof. Dr. Norina Forna and (c) preparing the PhD thesis.

Over time, the disciplines I taught changed in title and structure. Before their reorganization into the current configuration, I had the opportunity to have performed in the Department of Prosthodontics where I was involved in practical activities, in the following areas: *Gnathology* (3rd year), *Clinic and therapy of reduced partial edentulism* (4th year), *Clinic and therapy of extended partial edentulism* (5th year), *Complex oral rehabilitation*, *Implantology*, *Ceramic restorations in dentistry* and *Dento-somato-facial esthetics* (6th year), in both Romanian and English series. Even during that period, I had the chance to contribute to the lecture courses in *Ceramic restorations in dentistry* and even to teach it to the 6th year students.

During that early period, I also had the honor of a close cooperation with prof. Dr. Vasile Burlui and Prof. Dr. Norina Forna in writing three important books for our disciplines:

- *„Clinica şi terapia edentaţiei parţiale intercalate reduse”* - V. Burlui, Norina Forna, Gabriela Ifteni, Ed. Apollonia, Iaşi, 2001
- *„Clinical Guidelines and principles in the therapy of partial extended edentation”* - Norina Forna, V. Burlui, Ed. Alpha Centaur, 2001, Iaşi
- *„Clinica şi terapia edentaţiei parţiale întinse”* - V. Burlui, Norina Forna, Gabriela Ifteni – Ed. Alpha Centaur, 2004, Iaşi

I was also co-author of two chapters in a book written for a new-introduced discipline, Juventostomatology:

- “*Juventostomatologia*” – under the editorship of Prof. Dr. V. Burlui, Ed. Alpha Centaur, 2003, Iaşi, ISBN 973-9333-85-0:
    - chapter 18 – “Principles of treatment in fixed prosthodontics in young people” - Vasile Burlui, Valeria Pendefunda, Oana Ţănculescu
    - chapter 19 – “Treatment of extended edentulism in young people” - Norina Forna, Oana Ţănculescu, Monica Andronache

My involvement in the discipline research team, at that time, resulted in 32 communicated scientific papers, 23 published abstracts and 14 published papers in congress and conference volumes and journals.

I successfully defended my PhD thesis, coordinated by Prof. Dr. Vasile Burlui, in December 2004. I was extremely honored to get acknowledgement for several original contributions as: *DentPrep Software* created for assisting in choosing the type of the dental peripheral preparations for different types of cover crowns, the first *3D thermal finite-element analysis* (FEA) regarding the marginal deformations of metal-ceramic crowns consecutive to porcelain firing and *3D study by FEA* of biomechanical behavior of different types of crown margins in the context of different peripheral preparations using the *safety factor* according to Mohr-Coulomb theory. My hands-on knowledge in 3D modelling and FEA allowed me to create all the 3D models, in Rhinoceros Nurbs modeling software for Windows, and to run all the finite element analyses, in COSMOS DesignSTAR.

After the reorganization of the departments in our faculty, but also at the University level, my teaching activities took place within the discipline of Fixed Prosthodontics, part of the new department of Odontology-Periodontology, Fixed Prosthodontics, under the coordination of Prof. Dr. Gabriela Ifteni.

Fixed Prosthodontics addresses many disciplines within which I performed various activities, in accordance with my academic degree:

- clinical training in *Occlusology* and *Single-unit dental prothesis* (3rd year), *Fixed dental prothesis* (4th year), *Ceramic dental restorations* and *Dento-somato-facial esthetic* (6th year) in *Faculty of Dental Medicine*, for *Romanian*, *English* and *French* student series
- laboratory training in *Occlusology* and *Single-unit dental prothesis* (1st year), *Fixed dental prothesis* (2nd year), *Complex oral rehabilitation* and *Dento-somato-facial esthetic* (3rd year) in *College of Dental Technicians*
- lectures in:
    - *Occlusology* (3rd year - English section, 1st year - College of Dental Technicians) - between 2010 and 2011
    - *Single-unit dental prothesis* (3rd year – English and French sections) - since 2013 to present
    - *Single-unit dental prothesis* (3rd year - Romanian section) - since 2019 to present
    - *Fixed dental prothesis* (4th year - English section) - between 2013 and 2019
    - *Fixed dental prothesis* (4th year – Romanian section) - since 2020 to present
    - *Ceramic dental restorations* (6th year - English section) - between 2013 and 2019
    - *Dento-somato-facial esthetic* (6th year - Romanian, English and French sections) - between 2011 and 2012
    - post-graduate courses: *Ceramic Restorations* (2002), *Record and transfer of mandibulo-cranial relations on the simulator* (2009), *Dental technology master studies* (2013 - 2016)

The teaching activity was supported by various materials, developed as a result of my constant preoccupation to facilitate the transfer of knowledge to the benefit of students. Thus, I collaborated in the elaboration of textbooks, I developed teaching materials on electronic support, and I participated in software authoring.

Books and chapters in books:

1. *Prothèse Fixée Unitaire - Cahier d'activité pratique au simulateur* – Gabriela Ifteni, Norina Forna, Ed. U.M.F. "Gr. T. Popa", 2011, Iaşi, ISBN 978-606-544-059-3
    - Chap. 11 - *Méthode du couvrement. Préparation pour la couronne d'acrylate* - Oana Ţănculescu
    - Chap. 16 - *Masques de protection* - Oana Ţănculescu
2. *Examenul clinic în gnatologie* – Gabriela Ifteni, Alina Apostu, Oana Ţănculescu, Ed. U.M.F. „Gr. T. Popa" Iaşi, 2014, ISBN 978-606-544-230-6
3. *L'examen clinique en gnathologie* – Gabriela Ifteni, Alina Apostu, Oana Ţănculescu, Ed. U.M.F. „Gr. T. Popa" Iaşi, 2014, ISBN 978-606-544-230-6
4. *Clinical Examination in Gnathology* - Gabriela Ifteni, Alina Apostu, Oana Ţănculescu, "Gr. T. Popa" Publisher, U.M.Ph. Iasi, 2017
5. *Guidelines for Clinical Procedures in Single Unit Dental Restorations*, Edited by Gabriela Ifteni, Norina Consuela Forna, "Gr. T. Popa" Publisher, U.M.Ph. Iasi, 2017
    - Chap. 3. *Reconstitution method – Preparation of composed inlay cavities* - Oana Ţănculescu, Cristina Alina Cotea
    - Chap. 4. *Reconstitution method – Crown-root inlay / post-retained inlay crown* - Oana Ţănculescu, Alina Apostu
    - Chap. 9. *Coverage method – All-ceramic crown* - Oana Ţănculescu, Alina Apostu

- Chap. 11. *Coverage method - Temporary acrylate crown* - Alina Apostu, Oana Ţănculescu
- Chap. 15. *Restoration wax-up pattern* – Gabriela Ifteni, Oana Ţănculescu, Alina Apostu

6. *Patologia cavității orale* – Coordinators: Anca Chiriac, Liliana Foia, Editura "Gr. T. Popa" Iași, U.M.F. Iași, 2020, ISBN: 978-606-544-691-5
   - Chap. V.1. Afectarea orală în bolile reumatismale cu determinism imun – Codrina Ancuța, Cristina Pomîrleanu, Magda Antohe, Oana Ţănculescu, Cristina Iordache

Didactic materials on electronic support

1. DVD - Video demonstration: *Prepararea substructurilor organice – Demonstrație pe simulator* - Gabriela Ifteni, Oana Ţănculescu, Horia Aldea, Cristina Cotea, attached to the book „Practica preparării de substructuri organice în protezarea fixă unidentară" - Gabriela Ifteni, Norina Forna – Iaşi, Editura "Gr. T. Popa", 2009, ISBN 978-973-7682-83-3
2. DVD - Video demonstration: *Montarea în simulator – demonstraţie* – Oana Ţănculescu, 2009
3. CD - Examenul ortopantomografic – Oana Ţănculescu, 2009
4. CD - Examenul gnato-foto-static - Oana Ţănculescu, 2011

Software authoring:

1. *Application software for establishing the type of peripheral preparation* - ***DentPrep*** - Oana Țănculescu, Adrian Doloca, elaborated within the doctoral thesis, 2004
2. *Package of programs to assist the specific activity of a dental office* - ***DentalSuite*** - Oana Țănculescu, Sorina Solomon, Adrian Doloca, 2006
3. *Application software regarding the management of dental diseases in children and adolescents* - ***PedoDent*** - Oana Țănculescu, Iulia Cliveti (Aflorei), Adrian Doloca, 2009
4. *Application software for registering patients in the Dental Education Base* - ***Prodent*** - Norina Forna, Ciprian Branea, Oana Țănculescu, 2008
5. *Application software for the random selection of questions in the quiz tests* - ***SPINIT*** - Adrian Doloca, Oana Țănculescu, 2009
6. *Application software for evaluating the dento-somato-facial balance* - ***DSF - Software aesthetics*** - Oana Țănculescu, Alexandru-Marian Gavriluț, Adrian Doloca, 2010

At the same time, courses, laboratory guidelines and other multimedia resources used to support the teaching-learning process were uploaded to the E-learning platform and to the Microsoft Teams directories for open access.

In the e-learning medical education, one field of particular interest is that of Virtual Patients. It emerged in the past 15 years as a novel technology supporting medical training methods. Due to our interest in promoting an innovative educational tool which provides a safe environment in which students and interns can acquire clinical skills before engaging in real patient cases, we implemented the ***OpenLabyrinth*** platform, that can be access through our university e-learning platform. We authored few patients in different medical specialty and, moreover, I engaged students in authoring virtual patients in prosthodontics, creating new case-based-learning (CBL) and problem-based-learning (PBL) instruments.

As a result of actively encouraging students in participating in clinical, academic and research activities, more than 30 license theses in Romanian, English, and French sections and few awarded papers in scientific student manifestations and workshops were produced.

As part of my implication in students' activity I was assigned as a tutor for the 3rd year French students, between 2011 and 2017.

1.3. SCIENTIFIC RESEARCH ACTIVITY

I regard dental medicine as a sum of experiences and knowledge gained in domains that apparently have nothing to do with dentistry but for which enlightened and inspired minds find applications and in addition, made it an independent field. It is natural, and perhaps even mandatory, not to limit ourselves to the assimilation of barren notions and to the mechanical performance of therapeutic gestures, without understanding their substrate. It is also natural to try to go even further and keep our minds open to other areas that only help us to better understand and deepen the specialties in which we perform. The research activity itself, in fact, requires going above and beyond the scope of a field in order to be able to see through appearances.

The stomatognathic system is an adaptative system which is constantly subjected not only to environmental factors but also to supra- and sub-systemic factors, struggling for maintaining a good balance between risk factors and host factors. The correct identification and quantification of any factor impairing on this equilibrium is mandatory for choosing the correct therapeutical strategy. The fixed dental prothesis are meant to restore the integrity of the dental arch but also to restore the homeostasis of the stomatognathic system. The moment we choose to implement it is strictly related to the good or improved status of all the other systems and subsystems of the body. Therefore, the prosthodontist must integrate the information related to all the components of stomatognathic system – teeth, periodontium, oral mucosa, maxillary bones, TMJ, muscles and even to general condition. Therefore, my research has also an interdisciplinary aspect, focused on the local, loco-regional and general factors that can interfere with the balance of the stomatognathic system.

In the dental field there is a continuous pressure to increase the longevity of dental restorations. This pressure comes from patients / public, practitioners and administrative forums in the public health system. The continuous evolution of biomaterials and restorative techniques does not constitute absolute guarantees in ensuring therapeutic success. At the level of the oral cavity there is an extremely wide range of variables, difficult to quantify and to predict. The biomechanical behavior of restorations is an expression of these variables and, most often, responsible for the success / failure of the treatment.

Given my background in exact sciences ("Emil Racoviţă" High School Iasi - mathematics-physics profile) and the fact that over the time I have built on these skills due to the nature of the profession and my scientific interest, I can easily approach technical aspects, especially biomechanical and computer related subjects.

Therefore, my research activity covers the directions of the internal research plan of our discipline, aiming to improve both clinical practice and teaching dental health.

1. *Factors involved in homeostasis and dishomeostasis of stomatognathic system*
   - Modern approaches in the diagnosis and treatment of dysfunctional syndrome of the stomatognathic system (DSSS)
   - General condition and medication impact on stomatognathic system
   - Interdisciplinary approach of TMJ pathology in systemic context
   - Stomatognathic system adaptation to occlusion modifications
   - Stomatognathic system balance between function and esthetics
2. *Minimally invasive techniques in fixed prosthetic restoration*
   - Fibers reinforced-composite resins in fixed prosthetic restorations
   - Minimally invasive preparations for adhesive fixed prosthetic restorations
   - Clinical and technological factors with impact on marginal adaptation of indirect restorations
3. *Biomechanical behavior of different types of restorations and oral tissues*

- Fundamental in-vivo and ex-vivo studies on the structure and biomechanical behavior of oral tissues and dental and prosthetic reconstructions - elaboration of a clinical model
- Laboratory studies of the biomechanical behavior of oral tissues and dental and prosthetic reconstructions - elaboration of physical model and analytical model
- Computerized analyzes regarding the biomechanical behavior of oral tissues and dental and prosthetic reconstructions using 3D modeling and FEA - elaboration of the computational model.

Each of the four models brings new elements in understanding the biomechanical phenomenon and also to support the validity of the other models. I was interested in the behavior of oral tissues (periodontium, dental tissues, bone), direct dental restorations (fillings, splints) and indirect dental restorations (single unit indirect restorations, fixed dental prostheses).

4. *Information technology in dental medicine*
   - Creation and implementation of an IT platform for assisted learning and computerized assessment based on the concept of virtual patient
   - Implementation of different informatic systems in dental education and practice.

Achievements in the scientific publication area:

- Projects
  - Director - Evaluation of biomechanical behavior of fibre-reinforced composite bridges - Grant intern UMF Iasi - Contract no. 30880 / 30.12.2014
  - Member - Creation and implementation of an IT platform for assisted learning and computer evaluation based on the concept of virtual patient. Contract no. 29240/20.12.2013
- Book co-author - 3
- Book chapter author and co-author:
  - National book chapter author - 5
  - National book chapter co-author - 8
- Articles published in extenso in ISI Web of Science Core Collection indexed journals:
  - First / last / correspondent author - 16
  - Coauthor in ISI journals - 1
- Articles published in abstract in ISI Web of Science Core Collection indexed journals: 1, IF = 19,103/2010, Q1
- Articles published in extenso in international databases indexed journals:
  - First / last / correspondent author - 35
  - Co-author - 12
  - Articles published in extenso in national and international scientific meetings - 33
  - Oral presentations and posters at national and international scientific meetings - over 100
- Scientific awards:
  - *Efficacy of baricitinib on periodontal inflammation in patients with rheumatoid arthritis*. Joint Bone Spine. PN-III-P1-1.1-PRECISI-2020-50671. SECOND PRIZE in the competition "Awarding research results - Articles published in 2020" within Program 1, Subprogram 1.1 "Human Resources" by Order of the Minister of Education and Research no.5715/09.10.2020
  - *Volumetric Cone Beam Computed Tomography for the Assessment of Oral Manifestations in Systemic Sclerosis: Data from an EUSTAR Cohort*, J. Clin. Med. PN-III-P1-1.1- PRECISI-2020-50674. PRIZE I in the competition "Awarding research

results - Articles published in 2019" within Program 1, Subprogram 1.1 "Human Resources" by Order of the Minister of Education and Research no. 5715 / 09.10.2020
  - *Exploring the Role of Interleukin-6 Receptor Inhibitor Tocilizumab in Patients with Active Rheumatoid Arthritis and Periodontal Disease.* Journal of Clinical Medicine. PN-III-P1-1.1-PRECISI-2021-58086. PRIZE I in the competition "Awarding research results - Articles published in 2021" within Program 1, Subprogram 1.1 "Human Resources" by Order of the Minister of Education and Research no. 5715 / 09.10.2020
- Member of the editorial boards:
  - "*Journal of Romanian Medical Dentistry*", from July 2005 - 2009 - journal listed CNCSIS B + and indexed in international databases
  - “*Romanian Journal of Oral Rehabilitation*”, 2011 - 2014, journal listed CNCSIS B + and indexed in international databases
- International scientific visibility
  - Hirsch Index (Clarivate Analytics): 8
  - Number of publications in Clarivate Analytics database: 32
  - Cumulative Impact Factor from the last promotion: 23.399
  - Cumulative Impact Factor for all the activity: 28,972
  - Total number of citations without self-citations (Clarivate Analytics): 95
  - Average citation per item: 3.75
  - Hirsch Index (Google Scholar): 7
  - Number of publications in Google Scholar database: 66
  - ORCID: 0000-0002-0087-7190.

2. SCIENTIFIC ACHIEVEMENTS OF THE POSTDOCTORAL PERIOD

2.1. CUMULATIVE FACTORS INVOLVED IN MAINTAINING OR RESTORING THE BALANCE OF STOMATOGNATHIC SYSTEM

The stomatognathic system is a complex system with functions such as chewing, speech, swallowing, yawning, breathing and mimics.

The stomatognathic system is subdued to the general theory of systems enunciated by Ludwig von Bertalanffy [2], being characterized by the interaction between its elements, an interaction that creates its character of specificity and relative autonomy in relation with the human body. The stomatognathic system represents a synthesis of the component elements. It owns properties and actions which are not found in the elements outside the system, being equally dependent on the relationships established between the system and the component elements and structures, as a revers action of the system on the elements. Moreover, beside the internal relationships between the elements of the system (morphological, functional and clinical), the relations with the whole, the macrosystem, represented by the human organism in its entirety, to which the stomatognathic system is integrated, are of paramount importance. Integration itself involves the aspect of subordination at all levels, both for the stomatognathic systemic elements (odonto-periodontal units, manducatory muscles, temporomandibular joints (TMJ), maxillary bones, etc.) seen as subsystems, and for the stomatognathic system subordinated to the macrosystem, i.e. the human body in its whole [3].

As Burlui described it, the stomatognathic system has the following features [3]:

- *biologic system* – subdued to biologic laws
- *open system* – due to relationships between the macrosystem (human body), the stomatognathic system and subsystems (tooth, periodontium, muscles, vessels etc.)
- *system made by functional convergence* – each component (teeth, periodontium, maxillary bones, muscles, TMJ) with specific functions participate to global functions of the stomatognathic system
- *integral system* – none of the component elements can define the system, each element being necessary but not sufficient
- *integrated system* – intra- and suprasystemic relationships subordinate and integrate the activity of the stomatognathic system to the human body
- *self-regulated system* - the stomatognathic system is characterized by a specific homeostasis which is subordinated to the general, nonspecific homeostasis of the macrosystem (organism) and the feedback plays an important role.

Consecutively, the component structures of stomatognathic system emerge in a process characteristic for a complex adaptive system resulting in a mature stomatognathic system comprising of an interactive network of teeth, their occlusion and supporting tissues, maxillary jaws, TMJs, muscles, vessels, nerves, and salivary glands [4]. There is a physiological harmony between this structures, with fine-tuned balanced mechanisms meant to keep the optimal functions throughout the lifespan of the individual, in the context of constant exposure to mechanical and chemical environmental challenges [4-7]. Thus, the balance of the stomatognathic system, biological and biomechanical, is a dynamic process in relation to age, development, etc. Impairment of a single systemic stomatognathic component will, sooner or later, generate dishomeostasis of the entire system, stimulating, at the same time, its own rebalancing mechanisms, with the establishment of a new level of systemic equilibrium [3].

Damage to the components may be induced by injury or by treatments performed throughout the patient's life. Any lesion can evolve or become complicated and any intervention with iatrogenic potential can have an impact at local, loco-regional or even general level.

First as a practitioner and later as a researcher, I was deeply engaged in identifying possible factors involved in maintaining or restoring the balance of the stomatognathic system, whether local, loco-regional or general. Identifying and understanding these factors underlies the correct therapeutic conduct focused on the elimination of etiological factors and then the morphological and functional reconstruction. My interest in this direction guided my research in domains which are intrinsically connected with prosthodontics and dysfunctional syndrome - cariology, periodontology, and endodontics. Furthermore, the multidisciplinary research aimed also at the complex interplay between oral pathology, as chronic periodontitis, TMJ disorders, and immune mediated rheumatic pathology as well as at the impact of biological therapy on the articular and dental components.

2.1.1. LOCAL FACTORS INVOLVED IN STOMATOGNATHIC SYSTEM BALANCE

2.1.1.1. State of the art

The local factors involved in the dysomeostasis of the stomatognathic system are located at the level of dental, periodontal, muco-osseous and occlusal support. They interfere and condition the success of any type of treatment.

Modern requirements demand the dentist to perform prosthetic constructions that maintain or restore, simultaneously with the morphology and functions of dental arches, the biological balance - that harmonious coordination between the structure and function of tissues with which the prosthetic dental restorations come into contact directly or indirectly. The structures closest to the restorations obviously are the teeth and their periodontal support.

The prosthodontist needs to be aware of any sign of pathology related to these structures in order to amend it and even more, he/she needs to be updated with the latest developments in these areas, prosthodontics being often tributary to the technics and materials employed in connected dental fields, like cariology, periodontology and endodontics.

The occlusion and the temporo-mandibular dysfunction are another topic of interest in the specialty literature, conditioning the clinical success of any type of treatment.

I selected two of the many articles focused on local factors involved in stomatognathic system balance, for underlining the importance of systematic and knowledgeable approach of oral pathology and therapeutics.

Finishing and polishing are mandatory steps in resin-based restorations regardless of the technique used to restore the teeth. Regardless of the restoration type, direct or indirect, its contour is rarely perfect. The marginal adaptation of complete cover crowns is tributary to the quality of preparation surfaces, regardless of the type of luting agent used for cementation [8, 9]. Tooth preparations refined with finishing burs may favor the placement of restorations with the smallest marginal discrepancies, regardless of the type of cement used. Therefore, adjustments are usually necessary, especially at the margins of the restorations. The success or failure of a restoration is frequently related to the marginal adaptation, in the cervical area, the importance being emphasized by the existence of the marginal periodontium [10].

In most cases of restorations, these procedures demand the use of diamond and carbide burs that have the advantages of high efficiency and diversity of sizes and shapes. The excessive material should be removed and both the surface of the restorations and the junction with the adjacent dental tissues should be as smooth as possible in order to improve the aesthetic appearance and to avoid patient discomfort, staining, plaque retention and gingival irritation. Lots of studies were conducted in order to find the perfect instrument and technic for finishing composite resins and restorations margins [11-17] still limited information is available regarding the impact of these instruments on marginal adaptation and the iatrogenic trauma produced in enamel and dentin margins [18-22]. This is surprising as polishing of the restoration can significantly improve the surface after finishing procedures while the damage produced on the adhesive interface and adjacent dental surfaces might be irreversible. In the other hand, repeated use of finishing burs could induce surface roughness, microcracks, critical defects, and impaired adaptation of indirect restorations. Therefore, mastering the right technic is of major concern, considering the impact in clinical success of the restorations [16]. Using rotary instruments with high cutting efficiency for finishing the margins of the restorations involves high risks of abrading the adjacent tissues and damages the adhesive interface. Tungsten carbide and diamond burs are produced nowadays especially for finishing composite restorations, direct or indirect.

Periodontal disease affects irreversibly many individuals. According to the World Health Organization the prevalence of moderate periodontal disease varies between 2 and 67%, and of the severe form between 1 and 79%. Its bacterial etiology, as well as the anatomical peculiarities of the space it evolves give the importance of scaling and root planning (SRP) methods. The ability of the fibroblast to adhere to the root surface (which is essential for the periodontal regeneration) depends on the existence of a clean, non-toxic surface, free from bacterial plaque and calculus. Presently, the SRP represents the gold-standard of the periodontal therapy aiming to create a biologically acceptable surface for fibroblasts reattachment [23]. Its efficacy is well documented in systematic and narrative reviews [24-27] by the demonstration of gains in clinical attachment levels, reductions in probing pocket depths, and bleeding on probing scores [28].

There is an intense preoccupation and a growing interest in the development of more advanced instrumental techniques for SRP [29]. Numerous studies have investigated the effectiveness of classical instrumental methods such as SRP with Gracey curette compared with ultrasonic methods [30]. Ultrasonic instruments recently recorded a special development through the emergence on the market of specially designed perio-tips for deep pocket instrumentation up to 10 mm depth. A popular system in many Western countries but still lacking in Romania is the reciprocating system (Profin®) with Periotor inserts, developed by Axelsson in 1992. The set includes different types of inserts (Tor #1-6), adapted to plane, concave, convex but also to less accessible root areas.

	Most relevant personal scientific contributions in this field (the highlighted papers are presented in extenso in the next chapters)
ISI	1. Iovan G, Stoleriu S, Pancu G, Nica I, Sandu AV, Andrian S, Ţănculescu O. *Effect of Finishing Techniques on the Junction Between the Composite Restoration and the Dental Enamel*. Materiale Plastice 2017; 54 (2), 375-379 http://www.revmaterialeplastice.ro/pdf/39%20IOVAN%20G%202%2017.pdf 2. Saveanu CI, Tanculescu O, Anistoroaei D, Dragos O, Saveanu AE, Golovcencu L, Bamboi I, Hurjui LL. *Enamel Conditioning by Phosphoric Acid and Er.Cr: YSGG Laser Irradiation - EDS and SEM Studies* - Revista de Chimie, 2019, 70(9):3129-3131. IF = 1,605 https://www.revistadechimie.ro/pdf/8%20SAVEANU%209%2019.pdf

	3. Saveanu CI, Dragos O, Armencia A, Bamboi I, Saveanu AE, Tanculescu, O. *Characterization of Sealing Materials by Energy Dispersive X-ray Spectrometry and Scanning Electron Microscopy*. Revista de Chimie 2019;70(10):3657-3659 https://www.revistadechimie.ro/Articles.asp?ID=7616 4. Giuroiu CL, Andrian S, Stoleriu S, Scurtu M, Ţănculescu O, Poroch V, Sălceanu M. *The Combination of Diode Laser and Ozonated Water in the Treatment of Complicated Pulp Gangrene*. Appl. Sci. 2020, 10(12), 4203. IF = 2,474 https://doi.org/10.3390/app10124203 5. Solomon SM, Stoleriu S, Timpu D, Forna DA, Stefanache AM, Stefanache AM, Ţănculescu O, Ioanid N, Martu S. *E-SEM Evaluation of Root Surface after SRP with Periotor Tips*. Materiale Plastice 2016; 53 (4), 796-798 http://www.revmaterialeplastice.ro/pdf/SOLOMON%204%2016.pdf
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Book chapter	1. *Juventostomatologia* – sub redacţia Prof. Dr. V. Burlui, Ed. Alpha Centaur, 2003, Iaşi, ISBN 973-9333-85-0 • Cap. 18 - Principii de tratament în terapia conjunctă la tineri - Vasile Burlui, Valeria Pendefunda, Oana Ţănculescu • Cap. 19 - Tratamentul edentaţiei parţiale întinse la tineri - Norina Forna, Oana Ţănculescu, Monica Andronache 2. *Prothèse Fixée Unitaire - Cahier d'activité pratique au simulateur* – Gabriela Ifteni, Norina Forna, Ed. U.M.F. "Gr. T. Popa", 2011, Iaşi, ISBN 978-606-544-059-3 • Chap. 11 - Méthode du couvrement. Préparation pour la couronne d'acrylate - Oana Ţănculescu

- Chap. 16 - Masques de protection - Oana Ţănculescu

3. *Examenul clinic în gnatologie* – Gabriela Ifteni, Alina Apostu, Oana Ţănculescu, Ed. U.M.F. „Gr. T. Popa" Iaşi, 2014, ISBN 978-606-544-230-6
4. *L'examen clinique en gnathologie* – Gabriela Ifteni, Alina Apostu, Oana Ţănculescu, Ed. U.M.F. „Gr. T. Popa" Iaşi, 2014, ISBN 978-606-544-230-6
5. *Clinical Examination in Gnathology* - Gabriela Ifteni, Alina Apostu, Oana Ţănculescu, "Gr. T. Popa" Publishing House, U.M.F. Iasi, 2017
6. *Guidelines for Clinical Procedures in Single Unit Dental Restorations*, Edited by Gabriela Ifteni, Norina Consuela Forna, "Gr. T. Popa" Publisher, U.M.F. Iasi, 2017
   - Chap. 3. *Reconstitution method – Preparation of composed inlay cavities* - Oana Țănculescu, Cristina Alina Cotea
   - Chap. 4. *Reconstitution method – Crown-root inlay / post-retained inlay crown* - Oana Țănculescu, Alina Apostu
   - Chap. 9. *Coverage method – All-ceramic crown* - Oana Țănculescu, Alina Apostu
   - Chap. 11. *Coverage method – Temporary acrylate crown* - Alina Apostu, Oana Țănculescu
   - Chap. 15. *Restoration wax-up pattern* – Gabriela Ifteni, Oana Țănculescu, Alina Apostu

2.1.1.2. Odontal support - Effect of finishing techniques on the junction between the composite restoration and the dental enamel

Aim of the study

This study aimed: i) to evaluate the impact of finishing with diamond and carbide burs on the enamel adjacent to composite restorations and ii) to assess if the resistance of the enamel-resin junction to leakage is affected by these instruments.

Material and methods

In this study 40 extracted human molars were used. V class cavities were prepared in the buccal surfaces using a cylindrical diamond bur with water spray and high speed. The dimensions of the cavities were approximately 1.5mm depth, 4mm wide and 2mm high. All the margins of the cavities were prepared butt-joint in enamel. The cavities were cleaned with water and lightly air-dried using cotton pellets. The teeth were restored with a light-cured micro hybrid composite - G-aenial Posterior (shade A3) and a self-etch one component adhesive - G-aenial TM Bond (GC Corporation, Tokyo, Japan) using a bulk-technique. For shaping the restoration, Mylar matrix were applied during polymerization. The specimens were randomly distributed in 4 groups of 10 teeth. In 3 groups the restorations were finished using one of the tested rotary instruments as follows: group 1 – finishing with extra-fine diamond bur; group 2 - finishing with extra-fine carbide bur; group 3 - finishing with ultra-fine carbide bur (Table 1). Each restoration was finished for approximately 10s by the same operator. The rest of restorations were included in the control group.

The prepared specimens were rinsed with water and then stored in distilled water for 24 h. The apices of all teeth were sealed with a self-etching self-adhering flowable composite resin (Vertise Flow- Kerr) and then the external surfaces of each sample were covered with two layers of nail varnish except for the restoration and about 1mm around the tooth-restoration interface. The teeth were immersed in 1% methylene blue for 24 h and then washed under running water for 5 min. The prepared specimens were split in an axial mesio-distal direction. The surfaces of the enamel at the joint with composite resin were observed using a scanning electron microscope VEGA II LSH (Tescan Czech Republic) and photographs of representative areas were taken. After SEM examination, the samples were axially sectioned in buccal-lingual direction through the restorations. The images of the microleakages at the enamel margin were registered and scored using an optical Carl-Zeiss AXIO Imager A1m microscope, coupled with a high-resolution digital camera, capable to obtain images between 50 and 1000X, using Dark Field and Bright Field filters.

Table 1. Technical characteristics of the finishing instruments

Instrument	Band	Grit/Rotation per minute	Code/Manufacturer
Diamond Extra-fine Tapered, round-end	Yellow	20-30µm 300,000 r.p.m	TR-25EF ISO 199/016 MANI Inc, Japan
Extra-fine Straight-cut Tapered, safe end	Yellow	20 blades 160,000 r.p.m.	H 135SF-014-FG ISO 500314166041014 NTI Kahla GmbH, Germany
Ultra-fine Straight-cut Tapered, safe end	White	30 blades 160,000 r.p.m.	H 135UF-014-FG ISO 500314166031014 NTI Kahla GmbH, Germany

Dye penetration was evaluated according to a 4-point scale: 0 = no dye penetration; 1 = dye penetration from the cavosurface margin to less than half the length of the prepared wall; 2 = dye penetration from the cavosurface margin to more than half the length of the prepared wall, but not involving the axial wall; 3 = dye penetration from the cavosurface margin along the whole length of the prepared wall and also involving the axial wall. The scores were registered for each group and statistical analysis was performed.

Results

Results of the SEM study The SEM images supported the hypothesis that finishing of composite restorations with burs may result in superficial abrasions of the adjacent enamel irrespective of the type of the tested instrument. Most of the SEM images showed superficial scratches of the enamel surrounding the restoration, although all the tested instruments were classified as having extra-fine and ultra-fine grit and were specifically indicated for finishing procedures. The enamel injuries were in most cases superficial.

Fig. 1 shows the effect of the finishing burs on the joint between composite resin and enamel. When 200X magnification was used superficial scratches could be observed of the surface of enamel for the diamond extra-fine burs (Fig. 1a). In higher magnification the uneven appearance of the enamel surface was obvious, and scratches were noted also on the surface of composite (Fig. 1b and c). When the extra-fine carbide bur was used, the SEM images did not reveal significant irregularities in lower magnification (Fig. 1d). In higher magnification fine scratches were observed on the surfaces of enamel (Fig. 1e and f). For the ultra-fine bur, the cutting action resulted in smooth surfaces (Fig. 1g and h). Some irregularities were observed only when higher magnifications were used (Fig.1i).

The tested diamond burs had an extra-fine grit (20µm) while the tested carbide burs had 20 blades (super-fine) and 30 blades (ultra-fine). Although diamonds burs have a grinding action and the carbide burs have a cutting action, in our study both diamond and carbide burs produced superficial alterations of enamel. For the diamond bur, the scars could be seen when 200X magnification was used. For the carbide bur. the changes of enamel topography were observed in higher magnification (500X and 1000X) and consisted of superficial scratches with an inconsistent pattern. The inconsistency was probably related to the direction, force and time contact of the bur with the enamel. This higher variability of surface irregularities for finishing with carbide burs was also observed by previous studies that assessed the enamel topography following brackets removal [31, 32].

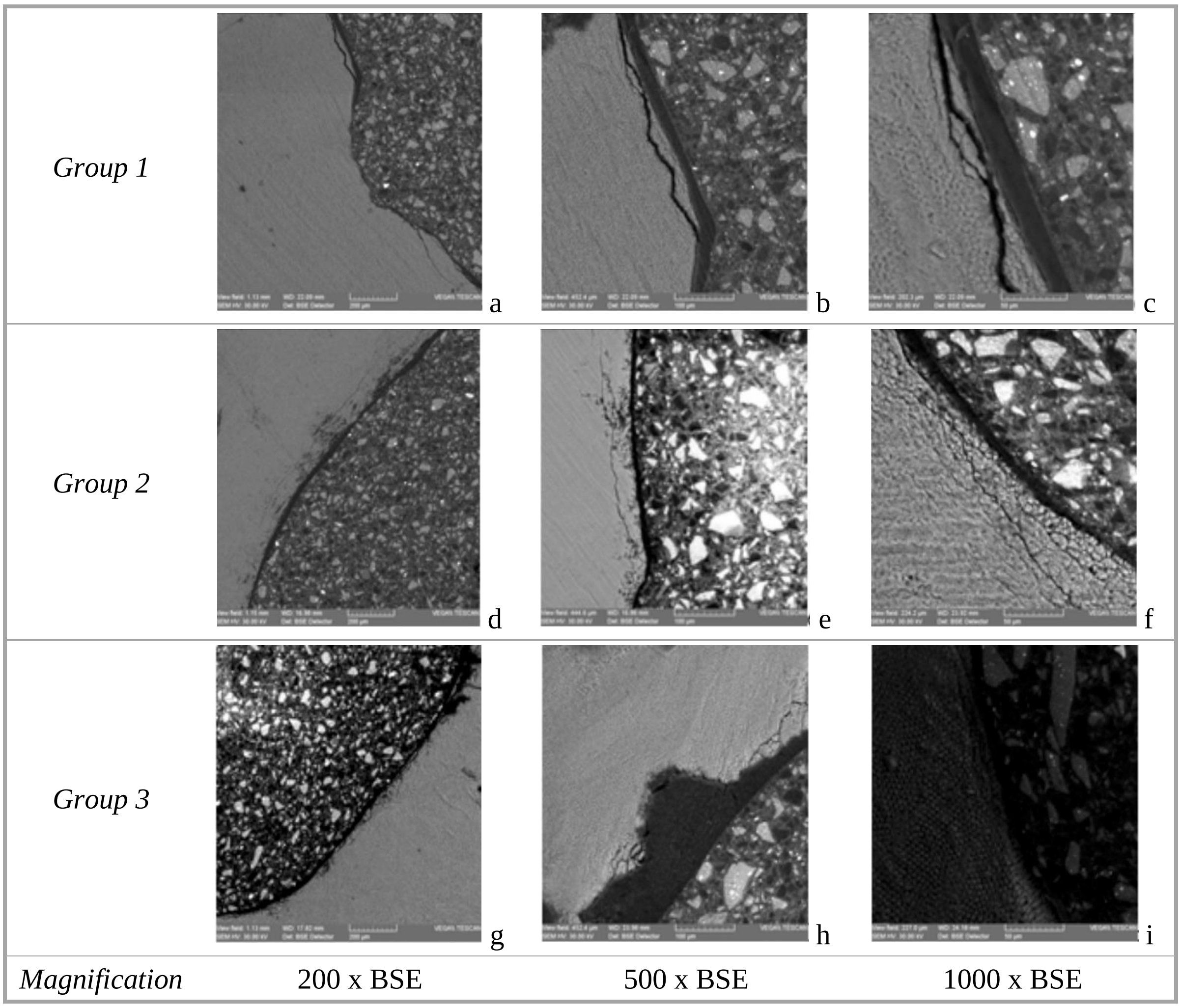


Fig. 1. SEM images of the joint between the enamel surface and composite resin for the study groups n (200X BSE, 500X BSE, 1000X BSE)

The results of the literature related to this subject are controversial; however, most of the authors agree that all burs produce injuries of enamel if they touch the surface.

The severity of these injuries varies from one study to another. Mitchell and co-workers quantified the loss of enamel surrounding class V restorations during finishing procedures and found that both ultrafine diamond and tungsten carbide burs resulted in iatrogenic abrasion of enamel, removing significantly more enamel than aluminum oxide disks [33]. On the contrary Schmidlin and Göhring concluded that both 8µ diamond burs and 40-fluted tungsten carbide finishers produced smoother surfaces and less finishing destructions than the other instruments under evaluation [18].

If carbide burs are less damaging than diamond burs is also a subject of controversy. Glazer considered that suitable types of carbide finishing burs have a clear advantage over fine-grit diamonds because they differentiate between composite and enamel, conserving the natural tooth structure. As a result, carbide finishing burs with a sufficient number of blades (10, 20 or 30) are expected to produce smoother surfaces than finishing diamonds [34], which support our findings.

In our study the pattern of scratching seemed different when higher magnifications were used and although both types of instruments resulted in minor injuries of enamel, in lower magnification (200X) the enamel scratches were more frequently observed when the extra-fine diamond burs were used comparing to carbide burs. These findings are also consistent with previous studies. Ferraris and Conti investigated the roughness of the composite–enamel interface when carbide burs and diamond burs were used for finishing composite. The investigated instruments were a tungsten bur with 16 blades and a diamond bur with a 46µm grit and then an ultrafine carbide bur (30 blades) and extra-fine and ultrafine diamonds burs (25 and 8µm). They concluded that the finishing procedures with fine grit gave a better smoothness with tungsten carbide burs compared to diamond burs. which support our findings [12].

In terms of number of blades a recent study did not find any difference of enamel roughness when 12-, 16- and 20- fluted carbide burs were used [35]. In our study the ultra-fine carbide burs seemed to scratch the least the enamel surface although in higher magnification (1000X), irregularities of the surface have also been observe which is in accordance with Campbell and Ulusoy [36, 37].

The apparent smoothness of the surface when carbide burs were used could be related to the ability of carbide burs to produce the least amount of irregularities, which was observed by other authors [38]. This relative smoothness might not imply that the cutting action is less invasive, only the roughness is decreased. This effect is anyway beneficial as it might decrease the risk for bacterial and stain retention on the surface.

The impact of the procedures on the adhesive joint could not be evaluated on the SEM images because the gaps and fractures could have been related with the experimental conditions that involved high stresses during cutting the specimens and vacuuming for SEM examination. It has been shown that a gap can appear wider after dehydration of dental tissues [38]. Therefore, a microleakage study was conducted afterwards.

Results of the microleakage study

Microleakage is the infiltration of bacteria, oral fluids and other materials between the tooth and the restorations. Dye penetration is the most common method used to assess microleakage in the dental literature [39]. The evaluations were carried out in a blind study to overcome the subjectivity of reading.

The mean values of leakage scores and standard deviation are listed in Table 2. Within each group there were samples showing a satisfactory marginal sealing, with no sign of marginal leakage at enamel margin. Scores 1 and 2 were also found in all the study groups and within the control group (Fig. 2). However, score 3, showing a deep penetration involving the axial wall, was not found in any of the specimens regardless the type of finishing instrument.

According to table 3 the mean values of the leakage scores for all the groups were Group 1 (1.20) > Group 2 (1.10) > Group 3 (1.00) > Control group (0.80). The relatively high mean scores registered for all groups could be explained by the technique of restoration and type of bonding agent that we used. The bulk-technique although it is simple and less subjected to variability develop a high polymerization shrinkage and consequently a high risk for adhesive failure and marginal gaps [40].

Also, for lowering the variables included in the study, we used a single-component bonding system applied in a self-etch technique which also might be responsible for the high scores of leakages. Bonding of one-step self-etch systems to enamel still remains critical and is controversially discussed by numerous authors [14, 41].

In order to determine if these differences were statistically significant, we used the nonparametric Wilcoxon signed-rank test which is the equivalent to the t –test for matched pairs. The results of tables 4 and 5 indicate the level of significance of this test.

When analyzing Z scores and the two-tailed probability values, it resulted that the differences between the three study groups were not statistically significant (Tables 4). The mean values of microleakage were higher for each of the tested instrument comparing to the control group. However, the statistical analysis showed that these differences were not statistically significant for any of the tested instrument (Table 5).

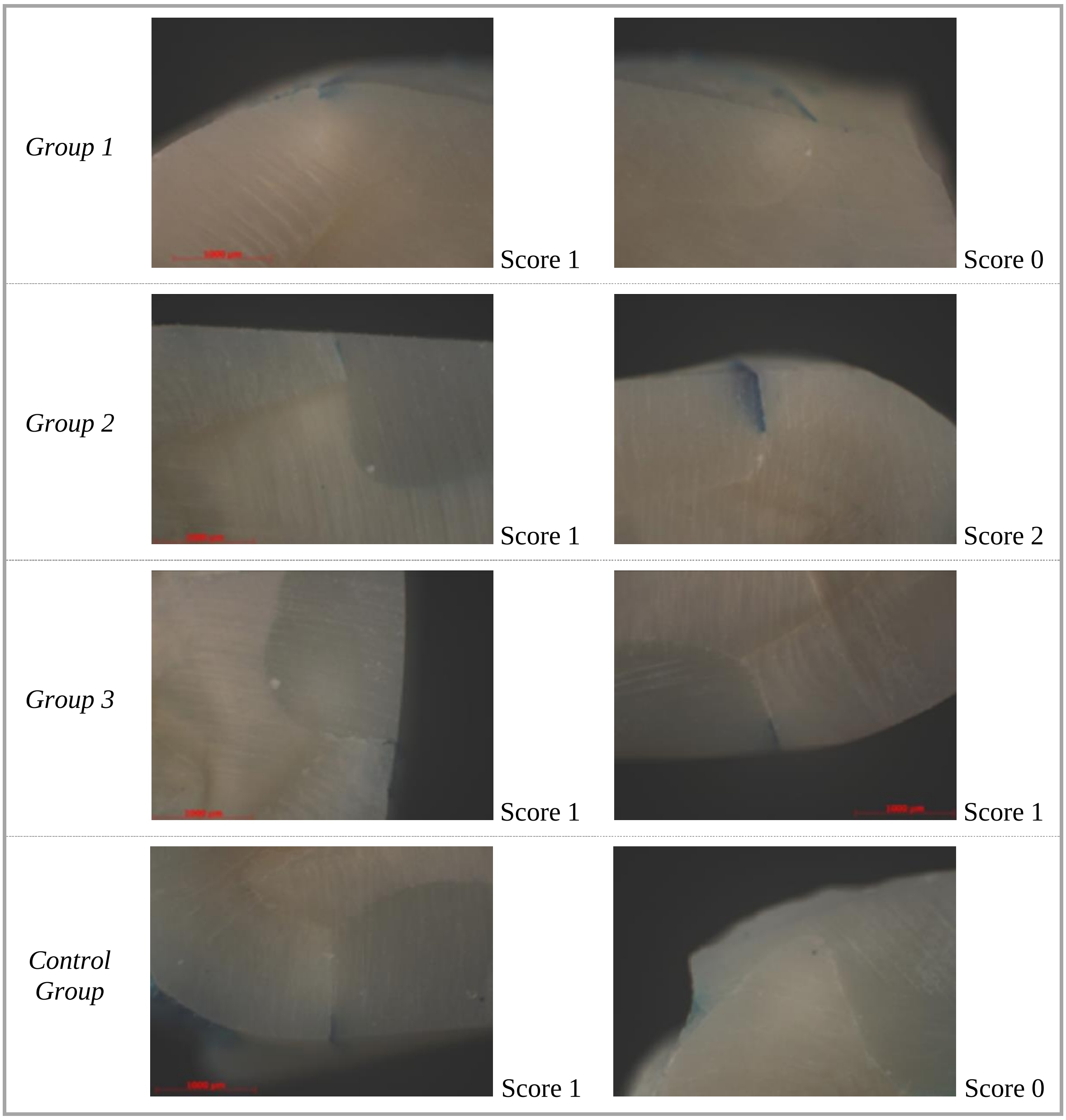


Fig. 2. Images of dye penetration between enamel and composite resin

Table 2. Microleakage scores in each group

Group 1	Group 2	Group 3	Control group
2	1	1	0
0	2	2	1
0	1	0	2
1	0	0	2
1	0	2	1
2	1	0	0
2	0	0	2
1	2	1	0
1	2	2	0
2	2	2	0

Table 3. Mean values of microleakage scores and standard deviations for each group

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Group 1	10	0	2	**1.20**	.789
Group 2	10	0	2	**1.10**	.876
Group 3	10	0	2	**1.00**	.943
Control group	10	0	2	**.80**	.919
Valid N (listwise)	10				

Table 4. Results of Wilcoxon test. significance level of comparison between the study groups

Test Statistics[a]	
	2 - 1
Z	-.250[b]
Asymp. Sig. (2-tailed)	**.803**
a. Wilcoxon Signed Ranks Test	
b. Based on positive ranks.	

Test Statistics[a]	
	3 - 1
Z	-.520[b]
Asymp. Sig. (2-tailed)	**.603**
a. Wilcoxon Signed Ranks Test	
b. Based on positive ranks.	

Test Statistics[a]	
	3 - 2
Z	-.378[b]
Asymp. Sig. (2-tailed)	**.705**
a. Wilcoxon Signed Ranks Test	
b. Based on positive ranks.	

Table 5. Results of Wilcoxon test. significance level of comparison between each study group and the control group

Test Statistics[a]	
	Control - 1
Z	-.933[b]
Asymp. Sig. (2-tailed)	**.351**
a. Wilcoxon Signed Ranks Test	
b. Based on positive ranks.	

Test Statistics[a]	
	Control - 2
Z	-.576[b]
Asymp. Sig. (2-tailed)	**.565**
a. Wilcoxon Signed Ranks Test	
b. Based on positive ranks.	

Test Statistics[a]	
	Control - 3
Z	-.183[b]
Asymp. Sig. (2-tailed)	**.855**
a. Wilcoxon Signed Ranks Test	
b. Based on positive ranks.	

Discussions

Microleakage at the tooth-restoration interface is considered a major factor in the longevity of dental restorations. It may lead to staining and a hastening of the breakdown at the restorations margins, as well as hypersensitivity, recurrent caries and pulpal pathology [42].

Finishing procedures might influence the joint between the margin of the restoration and adjacent enamel mainly because of the mechanical stress and heating during procedures. In order to decrease vibration which could generate microfracture in both enamel and composite, we used a new bur for every 5 restorations. For controlling heating and avoiding dehydration, the procedures were conducted with water spray.

The effect of the finishing procedures on the ability of composite restorations to seal the margins and to oppose micro-leakage was rarely investigated and even when it was the subject of research, usually the data were compared between different types of finishing and polishing protocols and did not involve a control group consisting of matrix-contoured restorations. More than that, the composite resins, the bonding systems, the dyes used for staining, the time of dyeing, and even the scoring methods are quite different from one study to another. All these variables make any comparison difficult and explain some contradictory results.

Some studies found that polishing technique had a significant influence while other concluded that finishing procedures have minimal impact on microleakage. Venturini and co-workers concluded that besides composite resin, the time and polishing technique had a significant influence on surface roughness, hardness and microleakage [43]. Another study evaluated the generation of enamel cracks and gaps at the cavosurface margin of resin composite restorations using various burs and concluded that the superfine-grit diamond bur generated fewer cracks and gaps than six-bladed tungsten carbide bur with air turbine [44]. Similarly, Maresca and co-workers found that fine, extra-fine and ultra-fine finishing diamond generated smaller gaps compared with laminated burs although the differences were not always statistically significant [45].

On the contrary, in our study the microleakage was lower for finishing with the carbide burs comparing to the diamond bur but the differences were not statistically significant although they could be related to the grit size (20-30µm for the diamond bur, comparing to 20, respectively 30 flutes for the carbide burs). Our results are consistent with a previous study that did not observe any significant difference in microleakage among different polishing technique and finishing techniques [19, 20]. Similarly, a previous study observed the effect of the finishing and polishing systems on microleakage only for the dentin substrate and no significant difference in leakage scores in enamel margins [46].

The control group in our study showed the least microleakage, although the differences were not statistically significant. However, it should be noted that in 4 control specimens there were noticed large amounts of composite resin overlapping the adjacent enamel (Fig. 2h). On one hand this extension of material moves away the restoration margin from the true limit of the cavity. Although this overhang apparently might protect the cavity wall from microleakage, it would be detrimental on long term because of the potential for retention and fracture. Future studies to investigate the impact of finishing in conditions of thermocycling and mechanical loading of the samples are necessary.

Conclusions

Finishing composite restorations with diamond and carbide burs resulted in abrasion of the adjacent enamel. Superficial scratches of enamel could be observed for extra-fine diamond and carbide burs. For the ultra-fine carbide burs, the irregularities could be seen only when higher magnification was used. Using carbide and diamond burs with high speed and water spray for finishing composite restorations did not seem to have a detrimental effect on the joint between enamel and composite resin. Microleakages were not significantly different between the restorations finished with the tested instruments and the restorations where only matrices had been used for contouring.

2.1.1.3. Periodontal support - E-SEM evaluation of root surface after SRP with Periotor tips

Aim of the study

The originality and novelty of this system prompted us in our study to compare root surface morphology obtained after SRP with Periotor inserts to that obtained by using Gracey curette and ultrasonic perio-tips.

Material and methods

Samples preparation

Thirty human teeth extracted due to periodontal reasons were selected for this study. A standardized procedure was used to perform the extraction of the teeth. The pliers were applied coronary, without taking any contact with the root surface, in order to maintain untouched the root surface. Before the extraction, the gingival margin was marked on the root surface using a fissure bur at high speed under continuous water cooling. After the extraction, the level of epithelial attachment was also marked using the same procedure. Thus, the experimental area used for instrumentation and evaluation was defined between the two marks. The extracted teeth were washed under running water and the periodontal tissue residues were removed using Gracey curette 5/6.

The teeth were decontaminated by immersion in 2.5% sodium hypochlorite solution for 15 min and then individually stored in 2 mL of saline at room temperature. After that the teeth were randomly distributed to three groups, according to the method used for root scaling.

Each scaling method was performed by one operator, trained and calibrated before the experiment for the specific method. In group 1 the root surface was instrumented using Gracey's curette 5/6 (Hu-Friedy Mfg. Co., Inc.) by applying 20 overlapping working strokes in vertical direction, with a 60-70° working angle and an appropriate pressure during the strokes. In group 2 the root surface was scaled using a periodontal tip mounted on an ultrasonic handpiece (PiezoSmart, Mectron) working at 25 kHz for 15 s (20 strokes) in a vertical direction under abundant water irrigation. In group 3 the root surface scaling was performed using a reciprocating instrument (Profin®) with Periotor inserts (Dentatus Ltd., Sweden) which are mechanically driven with reciprocating strokes of 1.4 mm length.

Samples evaluation

Evaluation of root surface morphology following SRP using the three methods was made by quantifying the presence of Root Surface Smear Layer (RSSL). All instrumented root surfaces have been evaluated using a new method – Environmental Scanning Electron Microscopy (ESEM) which offers high advantages: the desiccation of the samples is not necessary (this step can also generate artefacts, with high risk of errors), nor is the surface coating with gold-palladium, the samples thus being available for further and repeated investigations. This ESEM method, by our knowledge, has not been previously used in the assessment of the treated dental surfaces.

The micrographs were assessed by 2 examiners blinded to the experimental procedures but previously instructed during a pilot study to use the following index of Root Surface and Smear Layer Morphology, as follows: grade 1 - thick and compact smear layer, no dentin tubules open; grade 2 - thin smear layer, no presence of dentin tubules; grade 3 – residues of smear debris partially occluding dentin tubules; grade 4 - absence of smear layer on the dentin specimen. All instrumented root surfaces were fixed on aluminum supports and the surface morphology of the uncoated samples was examined using an environmental scanning electron microscope (ESEM) type Quanta 200 (FEI), operating at 20 kV with secondary electrons in low vacuum mode (60 MPa), with a large field detector.

Micrographs at four different magnifications (×200, ×1000, ×2000 ×5000) were recorded for each sample. The micrographs were evaluated by 2 examiners blinded to the experimental procedures but previously instructed during a pilot study to use the following Index of Root Surface and Smear Layer Morphology characteristics (IRSSLM, shortly RSSL), as follows: Grade 1 - thick and compact smear layer, no dentin tubules open; Grade 2 - thin smear layer, no presence of dentin tubules; Grade 3 – residues of smear debris partially occluding dentin tubules; Grade 4 - absence of smear layer on the dentin surface with exposed collagen fibrils. A single value was assigned for each sample after the evaluation of the representative images, resulting in 10 values per group and a mean value of the RSSLM was recorded in each group as a result of 10 samples values.

Results

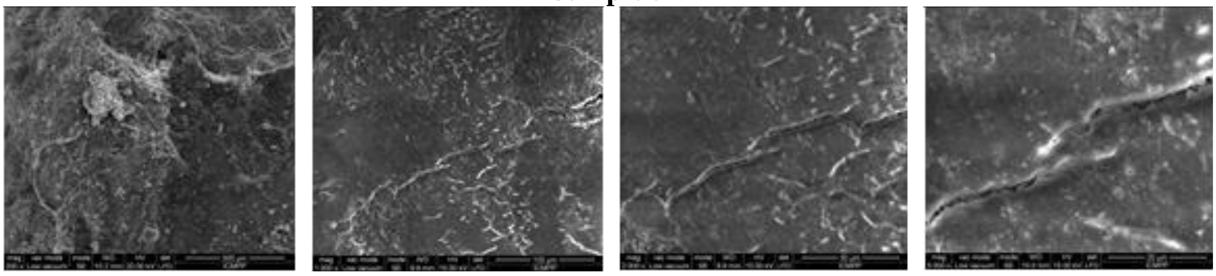
Examples of micrographs at four magnifications (×200, ×1000, ×2000 ×5000) registered for a sample in group 1 (sample a) and a sample in group 2 (sample b) are presented in Fig. 3.

After the examination of all micrographs at four magnifications (×200, ×1000, ×2000, ×5000), both examiners decided to use only the micrographs at ×200 magnification to evaluate the RSSL index due to the fact that at this magnification the entire evaluated area is visible. Examples of the samples micrographs evaluated with grade 1, 2, 3, and 4 according to RSSL index are presented in Fig. 4 (a, b, c and respectively d).

No large deposits of calculus were seen in all groups. Few calculus remnants were present in few samples of group 1 and 2. The presence of smear layer was noted in all three groups, more often observed in group 1. The ESEM evaluation of the samples also indicated that the surface of the samples of group 3 were smoother than those in group 1 and 2. An example of a sample in group 2 presented distinct scratches as a result of scaling instrument action is presented in Fig. 5. No irregular surface consisted in depression and elevations were present in group 3.

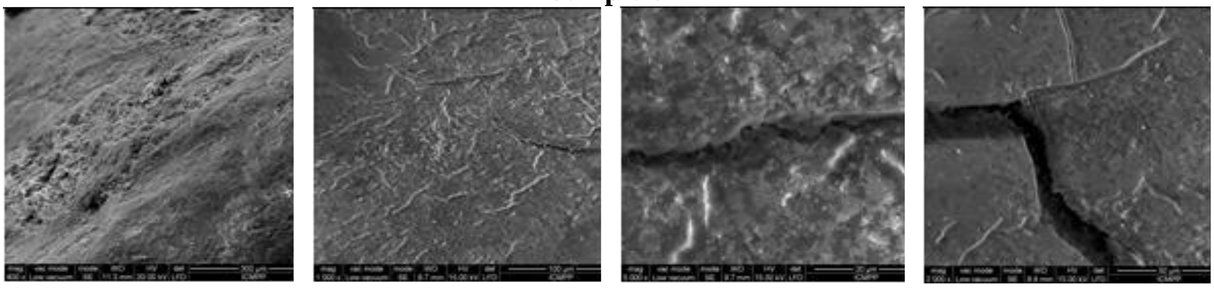
The total number of the score and the mean values of RSSL recorded for each group are presented in Table 6.

Sample a



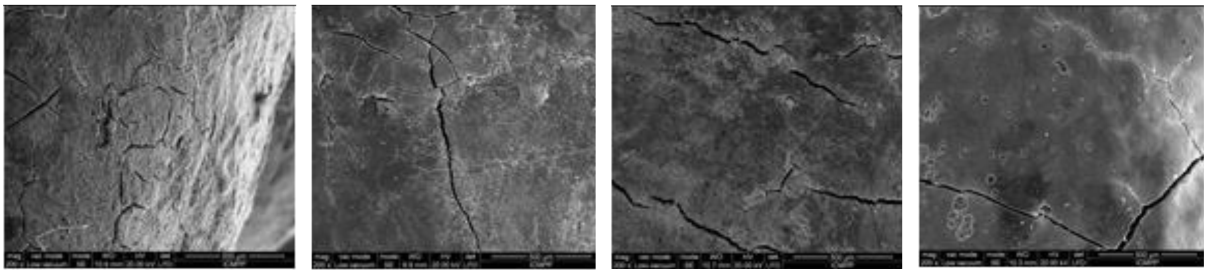
SEM x 200 SEM x 1000 SEM x 2000 SEM x 5000

Sample b



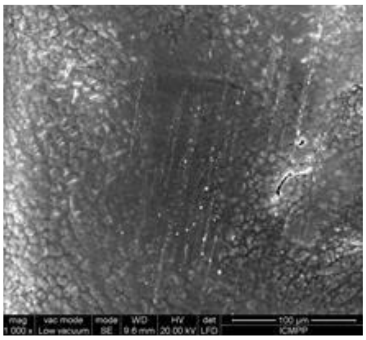
SEM x 200 SEM x 1000 SEM x 2000 SEM x 5000

Fig. 3. Micrographs at four magnifications registered for a sample in group 1



a. SEM x 200 b. SEM x 200 c. SEM x 200 d. SEM x 200

Fig. 4. Samples micrographs evaluated with grade 1, 2, 3, and 4 according to RSSL index



SEM x 200

Fig. 5. Micrograph of a sample in group 2 presented distinct scratches

Table 6. Total number of the score and the mean values of RSSL index

Groups	No.of samples	Total no. of scores				Mean RSSL
		1	2	3	4	
Group 1	10	5	3	2	-	1.7
Group 2	10	1	6	3	-	2.2
Group 3	10	-	4	6	-	2.6

Discussions

Previous studies suggested that more of the root surface removal was obtained by using curettes when compare with ultrasonic instruments [47]. This can be explained by the fact that the tips of ultrasonic instruments are thinner than the cutting edge of the hand instruments, in this way causing lesser damages on root surface. In our study the root morphology of many samples after curettes action presented distinct and even large area of dentine tubules opening because of an aggressive action of the instrument. Even a hand instrument delicately used have the potential to induce scratches and irregularities on the root surface due to the microscopic roughness of the cutting edge [48]. In this study no distinct tracks of instrument action were observed, probably due to calibrated pressure and to only vertical strokes applied by the operator. Ultrasonic instrumentation created only small irregularities characterized by several pits and partially covered by a thin and porous layer of debris. Also, other study concluded that ultrasonic technique determined the smoothest root surface when comparing the same three methods for SRP according to the surface morphology evaluated using AFM [49].

The presence of the smear layer on the instrumented root surfaces has been shown to act as a physical barrier between the periodontal tissues and the root surface [50, 51] unsuitable for reintegration in periodontal connective tissue. In our study the morphological aspect of root surface when using hand curette revealed a compact smear layer in many samples. The same results were also obtained in other studies [52]. Hand instruments often produce irregular pattern of root morphology, especially when combined horizontal and vertical strokes were applied. More than that, one of our previous study demonstrated that the use of Gracey curettes was the most aggressive method for SRP, leaded to the highest amount of dental hard tissues lost [53].

Conclusions

Our study showed that according to the root surface morphology evaluated using the RSSL index on micrographs obtained by environmental scanning electron microscopy (ESEM), the use of Periotor inserts mounted in Profin handpiece created smooth surfaces without organic debris and also without wide denudation of dentine. Almost similar root surface morphology was obtained using the ultrasonic scaling technique with special perio-tips and operating mode specially tuned for access to deep periodontal pockets up to 10 mm deep. The less quality of root surface morphology was obtained by using the hand scaling technique with Gracey curette, which leaded to extensive areas of dentinal tubules denudation and scratches.

2.1.2. LOCAL, LOCO-REGIONAL AND GENERAL FACTORS INTERPLAY INVOLVED IN STOMATOGNATHIC SYSTEM BALANCE

2.1.2.1. State of the art

Systemic sclerosis (scleroderma) is a chronic multisystem disease characterized by a dynamic and exclusively complex pathobiology directed by three essential processes: autoimmunity, widespread obliterative vasculopathy of small arteries causing ischemia-reperfusion injury, and varying degrees of inflammation and tissue fibrosis [54, 55].

The hallmark of this rare connective tissue disorder is its highly variable expression, with clinical phenotypes defined by different stages of disease expression, multiple organ involvement (lung, heart, kidney, gastrointestinal tract, and musculoskeletal system), and specific serologic biomarkers (anti-topoisomerase 1, anti-centromere, and anti-RNA polymerase III antibodies), resulting in significantly altered quality of life and survival rate [54, 55].

Although recent guidelines tried to redesign therapeutic strategies to prevent progression and to minimize damage of specific organ involvement, the management of scleroderma remains a challenge in routine practice [54, 55].

Oral health issues are commonly reported in patients with SSc (up to 80%) and comprise a broad spectrum of manifestations, from reduced mouth opening (microstomia) with abnormal interincisal distance and decreased salivary flow (xerostomia) to increased number of missing teeth and caries, periodontal diseases with gingival recession or other types of oral infections, and even temporomandibular joint involvement [54-60].

A number of explanations concerning the interfaces between SSc and oral health have been proposed; it seems that orofacial manifestations are generally related to excessive and extensive fibrosis of skin and oral mucosa, as well as to local vasculopathy [54, 56-60]. Likewise, poor oral hygiene prompted not only by local conditions (microstomia) and compromised gingival vascularization but also by hand disability as a result of sclerodactyly, acro-osteolysis, and/or small joint arthritis may compromise oral health [54, 55].

Since oral disease represents an additional contributor to altered quality of life [61] and dental treatment could be more difficult or, sometimes, unrealistic in advanced disease, routine oral assessment is indicated in scleroderma patients aiming at early detection and management of specific dental problems [62, 63].

Two major radiographic features are described in scleroderma, widening of the periodontal ligament (PDL) space [64-70] and mandibular erosions [66-69, 71-73].

PDL represents the soft tissue between the inner wall of the alveolar pocket and the roots of the teeth, consisting mainly of type I collagen and connecting the cementum of teeth to the gingivae and alveolar bone [68-70, 72, 74, 75]. A uniform widened PDL space at least twice as normal occurs in up to two-thirds of cases and is thought to be linked to an increased collagen synthesis in the ligament as a part of global fibrosis that characterize scleroderma and is not indicative of periodontal disease in the absence of occlusal trauma [67-69, 71, 72].

Bone erosions are identified at the sites of muscle attachment in the mandible: the masseter at the angle of the mandible, the lateral pterygoids at the condylar head, the temporalis at the coronoid process, and the digastric at the digastric region [67-70, 72].

Various papers have rated the frequency of such imaging abnormalities in SSc, mainly using two-dimensional radiographs [62, 67-70, 73], while the performance of Cone Beam Computed Tomography (CBCT) was assessed in few case reports [75-77].

Since three-dimensional (3-D) data reconstruction of the intraoral conditions using digital tools provide additional evidence to detect damaging manifestations within the oral cavity and is actually extensively used in the dental field for recognizing the location and severity of lesions in small anatomical regions (two or three teeth), we supposed that 3-D CBCT may also be useful to identify and, therefore, to better characterize scleroderma-related oral pathology [75-77].

The bidirectional relationship between periodontal disease and systemic disorders such as diabetes, cardiovascular and neurodegenerative disorders, chronic kidney disease, chronic obstructive airways disease, and immune-mediated rheumatic pathology, particularly rheumatoid arthritis (RA), is widely documented [78, 79].

RA and chronic periodontitis are multifaceted chronic inflammatory conditions characterized by complex cytokine signature, with joint inflammation and damage, periodontal inflammation with subsequent periodontal ligament and alveolar bone loss and gradual increase in tooth mobility, respectively [80, 81].

Both entities share multifactorial pathways including similar genetic background (HLA-DR antigens) and environmental factors (smoking), unbalanced activation of proinflammatory cytokines (TNF-α, IL-1β, IL-6, IL-17) and proinflammatory mediators (prostaglandin E2, nitric oxide), osteoclast activation (RANK overexpression) and dynamic articular and alveolar bone damage [78-84]. Furthermore, exposure to oral, lung and gut micro-biota, particularly to antigens generated during citrullination related to peptidyl arginine-deaminase enzyme produced mainly by Porphyromonas gingivalis but also by Aggregatibacter actino-mycetemcomitans may contribute to both RA and periodontal disease; hypercitrullination breaks the immune tolerance with induction of anti-citrullinated protein antibodies (ACPA) and promotes chronic inflammatory response in periodontal and synovial micro environments [78, 79, 85-88].

Increased risk of periodontitis is already reported in patients with RA, irrespective of disease duration [78, 79, 81], with a rate of 1.13 vs. controls according to a recent review [4]; overall, it seems that RA patients are prone to develop moderate periodontitis, with worsen periodontal status and more severe and aggressive lesions if early untreated compared to established disease [78, 79]. On the other hand, an association between chronic periodontal inflammation and the risk to develop RA was also advanced, new data proposing that periodontitis associated with P. gingivalis is more likely to be present in ACPA-positive at-risk adults without arthritis [86, 87, 89].

The emerging concept of dynamic link between RA and periodontitis suggests that aggressive management of rheumatic condition not only control articular inflammation and following damage, but also might modulate periodontal inflammation [78, 79, 90, 91]. Different papers investigated TNF and non-TNF biologics in periodontal disease with controversial and provocative results; indeed, TNF inhibitors, IL-6 receptor antagonist and even B-cells depletive agents are all able to improve periodontal status in early and established RA with periodontitis by reducing gingival and periodontal inflammation as well as tissues loss [78, 79, 84, 91-97].

We assumed that innovative small-molecule drugs that reversibly inhibit Janus-activated kinase (JAK)-dependent cytokine signaling (tofacitinib, baricitinib) recently approved for the management of moderate-to-active RA [98], may also have dual impact, on articular and periodontal disease, as they target intracellular pathways and modulate multiple cytokines [98]. However, only one paper has documented the benefits of tofacitinib on periodontitis in RA [99].

Rheumatoid Arthritis and Periodontal Disease Association

Rheumatoid arthritis (RA) is an autoimmune condition characterized by joint inflammation and destruction associated with chronic systemic inflammation accounting for significantly impaired quality of life. It is defined by the excessive activation of proinflammatory cytokines mediators, specific autoantibodies and progressive irreversible articular damage [100, 101]. Considered the hallmark of RA and, perhaps, the most important step in the pathobiology of the disease, the immune response against citrullinated peptides is driven, at least in part, by antigens derived from the periodontal tissue exposed to a dysbiotic oral microbiome during periodontitis [100-103].

Chronic periodontitis is a complex condition outlined by chronic inflammation and the subsequent damage of soft collagen-rich tissues progressing to periodontal ligament and alveolar bone loss as well as a gradual increase in tooth mobility [78, 80, 81, 100-105]. It is typically initiated by an infection with oral anaerobic bacteria followed by inflammatory and immune response in the gingival and periodontal microenvironment [100-102]. Autoantigens generated during citrullination induced by peptidylarginine-deaminase enzyme produced by Porphyromonas gingivalis (P. gingivalis), the keystone pathogen in the oral microbial biofilm, break the immune tolerance with induction of anti-citrullinated protein antibodies (ACPA) and promote chronic inflammatory response in both periodontal and synovial/articular tissues [84-87, 106-110].

Periodontal disease (PD) is generally associated with a broad spectrum of chronic systemic disorders including diabetes, cardiovascular, respiratory, kidney, and neurodegenerative diseases as well as immune-mediated rheumatic conditions [79, 100-103, 105]. Several epidemiological studies have already communicated that PD is more prevalent during RA and vice versa [103, 111, 112]. Indeed, patients with PD have an increased risk to develop RA, compared to general population, particularly those with a long history of more severe periodontitis, mostly explained by excessive protein citrullination [109, 113]. Furthermore, it seems that P. gingivalis positive-periodontitis is more likely to occur in ACPA-positive individuals without any arthritis, suggesting that PD may precede RA [86, 87, 103, 112, 113]. On the other hand, RA patients experience a greater risk of PD, irrespective of disease duration, especially in ACPA-positive subtype [78-81, 87, 100-102, 109]; moreover, they are prone to develop moderate to severe periodontitis in established compared to early disease [78-81, 83, 104, 109]. A detailed analysis of periodontal status in first-degree relatives of RA cases discovered a higher prevalence and severity of periodontitis in ACPA-positive RA [83, 104, 109, 114]. Altered periodontal condition during RA seems to be multifactorial, related to increased serum concentrations of proinflammatory cytokines and altered motor skills of the rheumatoid hand which can also contribute to compromised oral hygiene [100, 103, 105, 114].

This intriguing relationship between PD and RA is roughly supported by similar pathogenic pathways in a genetically predisposed host (human leukocyte antigen HLAhaplotype DRB1, HLA-DRB1, shared epitope) triggered by common environmental risk factors (cigarette smoking) [82, 84, 88, 100, 101, 103, 106, 115]. Important pathobiologic processes refer to the overexpression of proinflammatory cytokines (tumor necrosis factor alpha—TNFα, IL-1β, IL-6 and IL-17), inflammatory mediators (prostaglandin E2, nitric oxide) and degradation enzymes (matrix metalloproteinases 1, 8, 9, and 13), osteoclast activation, and progressive articular and alveolar bone damage [82-84, 88, 100, 101, 103, 106, 115]. Considered as the cytokine signature, the aberrant activation of TNF-α and IL-6 regulates immune response and bone metabolism in RA [81, 84, 100, 102, 105]; high concentrations of both cytokines were detected in serum, synovial tissues, as well as synovial fluids [94, 108], positively correlating with disease activity [116]. Different studies have also confirmed higher levels of potent IL-6 and TNF-α in inflamed gingival tissues, gingival crevicular fluid, and serum in patients with PD than in the healthy controls [107, 116-120]. Moreover, increased TNF concentrations are associated with less favorable periodontal indices such as bleeding on probing (BOP), probing pocket depth (PPD), and clinical attachment loss (CAL), while serum IL-6 concentrations decreased following periodontal treatment [94, 107, 116, 119, 121]. Surprisingly, salivary levels of TNF-α, IL-6, IL-8, and IL-17A can be affected not only by periodontitis but also in RA [111, 122]. Furthermore, the interplay between the subgingival biofilm, particularly PD-associated pathogens, and the host immune system may contribute to both PD and RA [100, 101, 108].

The Role of Different Therapies on Rheumatoid Arthritis and Periodontal Disease Outcomes

The evolving model for dynamic interrelation between RA and PD encourages the concept that standard management for RA may be effective in improving the outcomes in PD and vice versa [78, 79, 90, 91, 103, 109, 123]. Pivotal studies have already explored the role of different synthetic and biological therapies in active RA and comorbid periodontal disease, showing controversial results [84, 90, 91, 104, 105, 107, 110, 111, 115, 116, 122, 123]. Overall, there is a trend to consider that TNF inhibitors, IL-6 receptor antagonist, B-cells depletive agents and, even, JAK inhibitors improve periodontal health in both RA and other arthritis (e.g., ankylosing spondylitis, psoriatic arthritis); it seems that all these drugs are ultimately effective in decreasing gingival and periodontal inflammation and, to a lesser extent, associated tissue damage [84, 91-97, 99, 111, 116, 122-128]. Researchers even proposed a multistep approach of the sequential tissue repairing following TNF inhibitors, comprising reduced leukocytes traffic in the inflamed tissue, decreased proteolytic activity, and the normalization of osteoclast activity [100, 104, 105, 110]. However, there are differences among anti-TNF agents as only adalimumab and etanercept significantly improved periodontal outcomes in as rapid as six months, while infliximab worsened gingival inflammation but prevented gingival bone loss [105, 109]. Furthermore, according to a study by Kobayashi and colleagues, tocilizumab (TCZ) also ameliorates periodontal inflammation in RA with periodontitis as TNF inhibitors do [84, 94, 107, 111, 116, 119, 123, 129]. Its beneficial effects were potentially explained by the decrease in TNF-α serum levels as well as immunoglobulin G and serum amyloid along with a consistent impact on serum inflammatory mediators and indirect influence on periodontal inflammation [84, 94, 99, 107, 116].

On the other hand, several papers have addressed the effect of specific periodontal therapies (e.g., non-surgical scaling and root planning) on clinical RA activity in patients with chronic periodontitis with controversial results [98, 123, 130-135]. The most recent data from the ESPERA (Experimental Study of Periodontitis and Rheumatoid Arthritis) cohort failed to demonstrate clinical improvement in established RA following aggressive and intensive periodontal treatment [133].

	Most relevant personal scientific contributions in this field (the highlighted papers are presented in extenso in the next chapters)
ISI	1. Ancuta C, Pomirleanu C, Mihailov C, Chirieac R, Ancuta E, Iordache C, Bran C, Tanculescu O. *Efficacy of baricitinib on periodontal inflammation in patients with rheumatoid arthritis*. JOINT BONE SPINE, 2020, 87(3):235-239. DOI: 10.1016/j.jbspin.2019.12.003. IF = 4,929 https://europepmc.org/article/med/31962162 2. Ancuța C, Chirieac R, Ancuța E, Țănculescu O, Solomon SM, Fătu AM, Doloca A, Iordache C. *Exploring the Role of Interleukin-6 Receptor Inhibitor Tocilizumab in Patients with Active Rheumatoid Arthritis and Periodontal Disease*. Journal of Clinical Medicine. 2021; 10(4):878. IF = 4.242 https://doi.org/10.3390/jcm10040878 3. Iordache C, Antohe ME, Chirieac R, Ancuta E, Tanculescu O, Ancuta C. *Volumetric Cone Beam Computed Tomography for the Assessment of Oral Manifestations in Systemic Sclerosis*: *Data from an EUSTAR Cohort*, J. Clin. Med. 2019, 8, 1620; doi:10.3390/jcm8101620. IF = 3.303 https://www.mdpi.com/2077-0383/8/10/1620
IDB	1. Mârţu S, Zănoagă S, Rotaru M, Ţănculescu O. *The involvement of growth factors in the processes of periodontal repair and regeneration*. Journal of Romanian Medical Dentistry, 2008, 12(3):60-67, ISSN: 2066-6063 http://www.ijmd.ro/index.php?link=articole_vechi&anul=2008&nr=3&vol=12#Section14 2. Solomon SM, Tanculescu O, Scutariu MM, Pasarin L, Sufaru IG, Martu MA, Luchian I, Martu S. *On the periodontal status and oral hygiene in chronic kidney disease patients*. International Journal of Medical Dentistry. 2017, 21(4):290-293 https://www.ijmd.ro/wp-content/uploads/2019/07/ijmd_volume21_issue4_Sorina-Mihaela-SOLOMON.pdf 3. Iordache CM, Antohe ME, Dascalu CG, Fătu AM, Ancuța C, Țănculescu O. *Advanced imaging for the diagnosis and monitoring of temporomandibular joint*

	pathology in systemic sclerosis. Romanian Journal of Oral Rehabilitation. 2020;12(3):234-238 http://www.rjor.ro/advanced-imaging-for-the-diagnosis-and-monitoring-of-temporomandibular-joint-pathology-in-systemic-sclerosis/ 4. Iordache C, Ancuţa C, Ancuţa E, Ţănculescu O, Surlari Z. *Posture and Vertebral Pathology Issues in Dental Practice*. Romanian Journal of Oral Rehabilitation, 2012, 4(1):74-80 http://www.rjor.ro/2012/posture-and-vertebral-pathology-issues-in-dental-practice.html?lang=ro
Carte	*Patologia cavității orale* – Coordonatori: Anca Chiriac, Liliana Foia, Editura “Gr. T. Popa” Iași, U.M.F. Iași, 2020, ISBN: 978-606-544-691-5 • Cap. V.1. Afectarea orală în bolile reumatismale cu determinism imun – Codrina Ancuța, Cristina Pomîrleanu, Magda Antohe, Oana Țănculescu, Cristina Iordache

2.1.2.2. Volumetric cone beam computed tomography for the assessment of oral manifestations in systemic sclerosis: data from an EUSTAR cohort

Aim of the study

This study aimed to assess oral radiologic manifestations associated with scleroderma using high-resolution CBCT and to identify potential relations with disease variables.

Material and method

We performed a cross-sectional study in a cohort of forty-three consecutive patients fulfilling either the old 1980 ACR (American College of Rheumatology) criteria or the recent 2013 ACR/EULAR (European League Against Rheumatism) classification criteria for SSc, attending at least once the outpatient rheumatology department (Clinical Rehabilitation Hospital of Iasi, Romania) during a twelve-month interval (January 2017 - January 2018). Additionally, forty-three sex- and age-matching controls were recruited from patients addressing osteoarthritis at the same department.

The study was approved by the ethics committee board of Clinical Rehabilitation Hospital of Iasi, and subjects provided written informed consent before enrolment.

Patients underwent rheumatologic and routine oral health evaluation; in addition, all individuals were referred for dental radiographic evaluation.

a. SSc-Related Parameters

Specific scleroderma data comprised different variables as defined by the standard requirements promoted by EUSTAR (European Scleroderma Trials and Research Group) and included subset classification, meaning limited or diffuse cutaneous SSc based on their skin extent (LeRoy classification criteria); disease duration; clinical profile (modified Rodnan skin score 0–51, digital vasculopathy and other visceral involvement); antibody profile (anti-topoisomerase-1, anti-centromere antibodies, and anti-RNA polymerase III); disease activity (revised EUSTAR activity index (0–3)); and severity (Medsger disease severity scale; 0–4) [55, 74, 136, 137].

Limited cutaneous SSc (lcSSc) was defined as skin involvement distal to the elbows and knees, while diffuse cutaneous SSc (dcSSc) as skin involvement proximal to the elbows and knees, with or without truncal involvement [54, 55].

b. *Oral Manifestations*

Detailed oral examinations were conducted at the Dental Learning Clinical Department of Grigore T. Popa University of Medicine and Pharmacy Iasi, Romania, and included dental and periodontal measurements according to a standardized plan, e.g., interdental distance, number of missing teeth, restored teeth, carries and periodontal indices performed by two trained dentists aiming to identify pathological tooth migration, occlusal trauma, periapical pathology, and periodontal disease.

Interdental distance was calculated between the incisal edge of the lower central incisor tooth to the incisal edge of the upper central incisor [67, 68, 70, 138]. Plaque accumulation reflecting oral hygiene status was recorded with a Silness and Loe plaque index (PI), while gingival index (GI) was used to measure the extent of inflammatory gingivitis [139]. Both indexes were evaluated as degrees from 0 to 3 [140] and also the percentage of sites with detectable plaque (Pl%) and with bleeding on probing (BOP%) [141].

Periodontal status was appreciated by periodontal probing depth (PPD), the distance from the gingival margin to the base of the gingival sulcus, and by clinical attachment level (CAL), the distance on the buccal or labial surface from the cementoenamel junction to the base of the gingival sulcus [67-70, 142, 143]. We used a custom periodontal chart that included the measurement of the gingival recession and the pocket depth in 4 points (mesiobuccal, distobuccal, mesiolingual, and distolingual) for each tooth, assessed with a periodontal probe marked in millimeter intervals [75].

The presence of periodontal disease in a given tooth was defined as either a PPD > 3 mm or a CAL_5.5 [67-70, 141, 142]. The extent of periodontal disease in the entire mouth was calculated as the number of involved teeth [67-70], and the severity (no, mild, moderate, or severe periodontitis) was also assigned accordingly [67-70].

Temporomandibular joint (TMJ) involvement (pain, sounds, and mobility) was also recorded.

c. *Imaging Studies*

All patients had a detailed radiologic analysis meaning conventional radiographs and an upper and lower jaw volumetric CBCT, focusing on the width of the periodontal ligament space and the presence of mandibular erosions.

Radiographically, PDL occurs as the radiolucent space between the lamina dura and the tooth root; its normal width ranges between 0.15 mm and 0.21 mm and decreases with age [75]. The presence of a widened PDL was recorded on both panoramic radiographs and CBCT and appreciated as widening near the coronal portion of the root or in the periapical region in either one of both sides of the root [67-70].

Orthopantomogram (OPG) offers a preliminary assessment of both teeth and temporomandibular joint and were preferred; however, bitewings (used for the detection of caries, inflammatory pulp changes, and proximal periodontal irritant factors) and periapical radiographs (for only 2 to 3 teeth) were also performed in selected cases (protocol adapted from Canadian Oral Health Study) [67-70].

Since 3-D analysis of the oral cavity facilitates the evaluation and diagnosis of different intraoral conditions including TMJ and different periodontal issues, 3-D CBCT was systematically done in all subjects. CBCT provides additional data for the accurate assessment of the buccal and oral alveolar bone of which the resorption is not visible on panoramic images and is also recommended for the visualization of mandibular condyle as well as for the complete evaluation of the periodontal space emphasizing areas with maximal alveolar bone loss.

The CBCT scanner used was Planmeca Promax 3D Mid (Planmeca OY, Helsinki, Finland). Images were obtained at 90 kV and 12 mA with a 0.2 voxel size, and the typical exposure was 5.4 s. NNT®NewTom software (Quantitative Radiology, Verona, Italy) was used to evaluate the CBCT images. Sagittal and coronal (1-mm thickness) as well as axial sections (0.5-mm thickness) of the condyle were evaluated.

Readings was performed by the same trained oral radiologist.

PaX-i3D Green CBCT (Vatech, Hwaseong, Korea) and Ez3D Plus Professional CBCT software (Vatech Co., Hwaseong, Korea) (version 1.2.6.23) were used as 3D viewer and image analysis software.

Images were obtained at 94 kV, 7 mAs, 0.120 voxel size, 9-s exposure time, 1–0.5-mm slice interval, and 0.5 - 0.2 mm slice thickness.

The CBCT measurements were done on the teeth without clinical signs of active periodontitis, occlusal trauma, or pulpal injuries.

In the first step, it was checked if CAL < 5 mm and the lamina dura is present. The measurements were initially made on the coronal and sagittal sections, from the cementoenamel junction to the alveolar crest. If CAL > 5 mm, the tooth was included in "periodontal group". Subsequently, on 3-D reconstruction, the areas with resorption potentially greater than 5 mm were identified. The measurements were made at those levels, completing the measurements in axial and sagittal plane, and if they were larger than 5 mm, the tooth was included in "periodontal group".

In the next stage, the periodontal space measurement was performed on axial sections in the cervical, middle, and apical third of the clinical root, considering the perpendicular between the root surface and the lamina dura. In the cervical third, the PDL space was evaluated in 8 points: in the middle of each root face (buccal—B, oral—O, mesial—M, and distal—D) and at the transition angles (MB, DB, DO, and MO). In the middle and apical third of the clinical root, the measurements were made on the middle of each root surfaces. Additionally, the evaluations were completed with an apical measurement on the sagittal or axial section from the tip of the root to the lamina dura in the cervico-apical direction (apical periodontal space).

For the multirooted teeth, measurements were added at the furcation level on the sagittal or axial section in the cervico-apical direction. For each region, the average was determined. We were interested only in teeth with regularly widened PDL without any marginal or apical periodontal lesion; for a cervically enlarged PDL, we searched for potential putative factors (e.g., occlusion trauma, orthodontic tooth movement, irritative mechanical, or chemical factors) and excluded it from the final analysis. Occlusal trauma was clinically identified by abrasion facets, premature contact points, or interferences in static and dynamic occlusion.

Patients with a history of orthodontic treatment were not enrolled in the study.

Mandibular erosions (condyles, coronoid processes, digastric regions, and posterior rami) were also recorded using panoramic radiographs and CBCT sections as well and rated by using a Likert-type scale from 1 to 5, from "definitely no erosion, 0" to "definitely erosion, 5", that was adapted from [67-70].

d. *Statistical Analysis*

Descriptive statistics were used for scleroderma parameters and radiologic manifestations of the patients with SSc and the controls. Nonparametric statistics (Spearman rank correlation; univariate and multivariate analysis adjusted for age, gender, and smoking status) were used to analyze the association between SSc and number of teeth with widening of the PLS and erosions. Mann Whitney U tests, Chi-squared tests, and Fisher's exact tests were used accordingly.

All statistical analyses were performed using SPSS (Statistical Package for Social Sciences) v.20 IBM statistics (IBM Corp., Armonk, NY, USA) with p-values < 0.05 being considered statistically significant.

Results

a. SSc-Related Characteristics

We enrolled 43 subjects with scleroderma as follows: mainly women (72%, n = 31), with a mean (SD) age of 43.95 (11.36) years and a mean (SD) disease duration of 8.7 (4.5) years; 67.74% (n = 29) had diffuse disease, and 53.48 % (n = 23) were anti-topoisomerase 1 positive SSc; and the mean (SD) disease severity was 4.8 (2.1) (Table 7).

The same number, sex, and gender of matching controls were recruited.

b. Oral Health

We demonstrated a reduced maximal mouth opening in 69.76% patients (n = 30) and a mean (SD) inter-incisal distance of 32.5 (7.2) mm, smaller than normal ($p < 0.05$).

The mean (SD) number of evaluable teeth was 23.5 (4.2) in SSc and 29.6 (2.1) in controls, respectively, with a trend to have more missing teeth in patients with SSc; moreover, these individuals were significantly more likely to be edentulous than matching controls (Table 7).

At n = 27, 62.8% of SSc experienced one or more caries, and more than half of patients (53.48%, n = 23) presented with periodontal disease.

Table 7. Systemic sclerosis (SSc)-related parameters, clinical oral, and radiographic features.

Parameter	No (%) or Mean ± SD
Demographics	
Female	31 (72)
Age	43.95 (11.36)
Smoking status	10 (23.25)
SSc-related measures	
Diffuse cutaneous SSc	29 (67.74)
Disease duration	8.7 (4.5)
Modified RODNAN (0–51)	18 (10.1)
Facial skin score (0–3)	1.5 (0.7)
Serology	
Anti-SCL70	23 (53.48)
Anti-centromere B	10 (23.25)
Dental issues	
Missing teeth per subject	9.3 (4.5)
Teeth with periodontal disease	7.2 (3.4)
PDL space widening	
Patients with uniform PDL space widening	20 (46.51)
Apical PDL space widening (mm)	0.35 (0.16)
Erosions	
Patients with mandibular erosions	10 (23.25)
Number of subjects with condylar erosions	8 (18.60)

PDL = periodontal ligament.

Significantly higher plaque accumulation was found in SSc, up to 50% of patients displaying sites with detectable plaque: 0.75 (0.39–1.51) vs. 0.39 (0.24–0.61) in controls ($p < 0.05$). Furthermore, gingival inflammation was found in 67.44% (n = 29) cases, while 55.81% of scleroderma patients (n = 24) presented with bleeding on probing.

For n = 14, 32.55% SSc had periodontal pockets and 27.9% (n = 12) had a CAL _ 5.5 mm; mean (SD) PD was significantly different in scleroderma compared with controls: 5.21 (0.25) mm vs. 3.15 (0.37) mm, $p < 0.05$. Severity of periodontitis was also meaningfully different in SSc vs. controls ($p < 0.05$), with severe disease described in up to one third of scleroderma and related periodontal disease (Table 8).

Likewise, considerably more SSc presented clinical symptomatic TMJ involvement (n = 18) as compared with controls (n = 7) (p < 0.05).

c. Imaging Studies

Panoramic radiographs were performed in all cases to allow a basic assessment of the mandibular erosions and to select teeth suitable for further CBCT evaluation. Both panoramic radiographs and CBCT sections showed the widening of the PDL space, several remaining roots, and dental caries; in addition, mandibular erosions, even condylar lysis, were described, particularly using CBCT exams.

d. PDL SpaceWidening

Panoramically reconstructed CBCT demonstrated widening of the PDL in at least one tooth in 46.51% SSc (n = 20) vs. 13.95% (n = 6) controls (p < 0.05). Mean (SD) periapical PDL width was 0.35 (0.16) mm, about twice the normal thickness, and 0.17 (0.04) mm in controls (p < 0.05).

Although both anterior and posterior teeth were involved, a wider PDL was commonly found in the posterior region (p < 0.05). Nevertheless, the molars and premolars presented with the most significant differences between scleroderma and controls (p < 0.05).

Multivariate analysis adjusting for age, gender, and current smoking status confirmed the important difference between the two groups (OR 7.26; 95% CI 3.87 - 13.65). Moreover, there were significantly more teeth with widened PDL in scleroderma patients than in controls as suggested by univariate and multivariate statistics: 1.21 (2.31) vs. 0.28 (0.25) (p < 0.05), with relative risk (RR) 8.51; 95% CI 5.37 - 12.61), respectively.

Table 8. Associations between scleroderma-related parameters and oral radiographic abnormalities (univariate analysis).

Parameter	PDL Widening		Erosions	
	RR	*p*	RR	*p*
Demographics	1.1	$p > 0.05$	1.2	$p > 0.05$
Female	1.43	$p > 0.05$	1.1	$p > 0.05$
Age				
Smoking status	1.06	$p > 0.05$	1.06	$p > 0.05$
SSc-related measures				
Diffuse cutaneous SSc	1.25	$p > 0.05$	1.02	$p > 0.05$
Disease duration	2.36 *	$p < 0.05$	0.98	$p > 0.05$
Modified Rodnan (0–51)	3.12 *	$p < 0.05$	1.3	$p > 0.05$
Facial skin score (0–3)	2.71 *	$p < 0.05$	1.02	$p > 0.05$
SSc activity	1.21	$p > 0.05$	1.17	$p > 0.05$
SSc severity	3.09 *	$p < 0.05$	0.92	$p > 0.05$
Interdental distance	1.21	$p > 0.05$	3.51 *	$p < 0.05$
Dental issues				
Missing teeth per subject	1.02	$p > 0.05$	0.87	$p > 0.05$
Teeth with periodontal disease	1.15	$p > 0.05$	1.12	$p > 0.05$

RR, relative risk; PDL, periodontal ligament; * $p < 0.05$.

No calcification within the PDL space was demonstrated.

Figure 6 presents examples of PDL space measurements.

e. Erosions

Additionally, erosions of the mandible were described in 23.25% (n = 10) of scleroderma cases (Table 7, Fig. 7 and 8), with the majority of patients presenting with at least one condylar erosion; the mean (SD) number of sites with bone erosions was 0.42 (0.5).

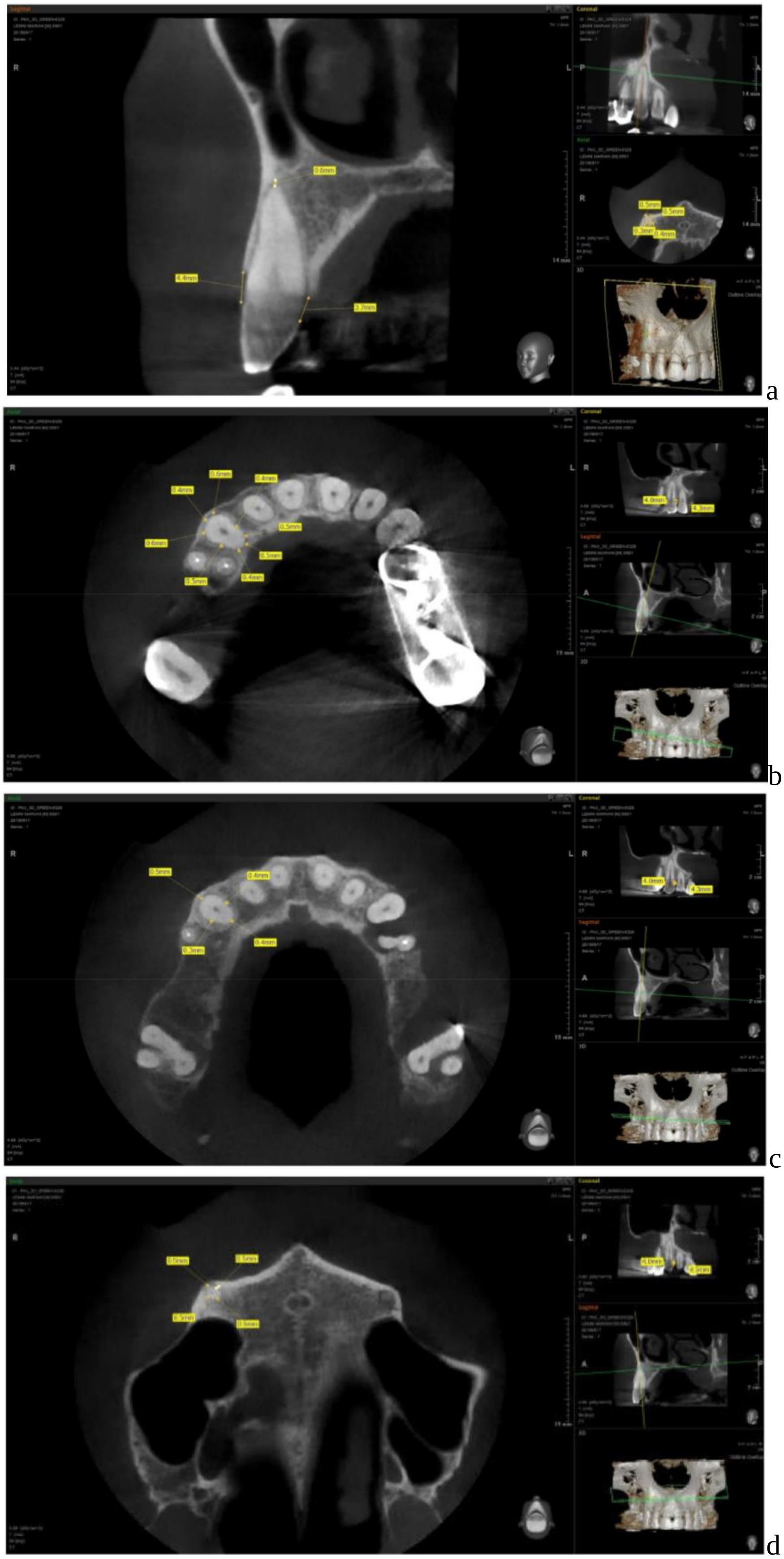


Fig. 6. Measurements of periodontal ligament space on cone beam computed tomography (CBCT): (a) clinical attachment level (CAL) and apical PDL space measurements; (b) 8-point cervical third measurements; (c) 4-point middle third measurements; and (d) 4-point apical third measurements.

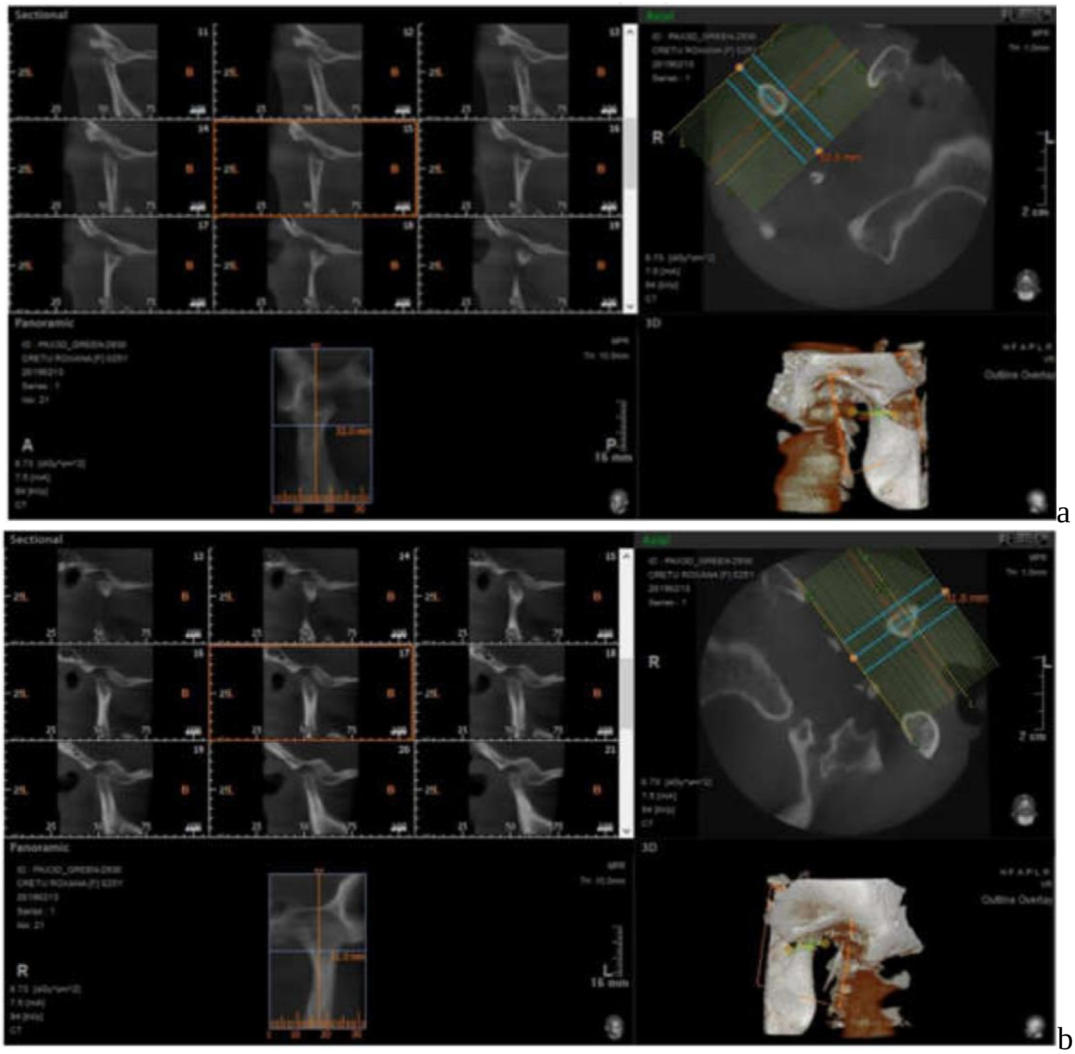


Fig. 7. CBCT aspects of the (a) right and (b) left temporomandibular joint (TMJ).

Overall, patients with SSc had more mandibular erosions, irrespective of the locations (condyle, coronoid process, or otherwise) vs. controls (23.25%, n = 10 vs. 6.97%, n = 3, $p < 0.05$) as demonstrated by multivariate analysis (OR 5.32; 95% CI 1.87–11.74).

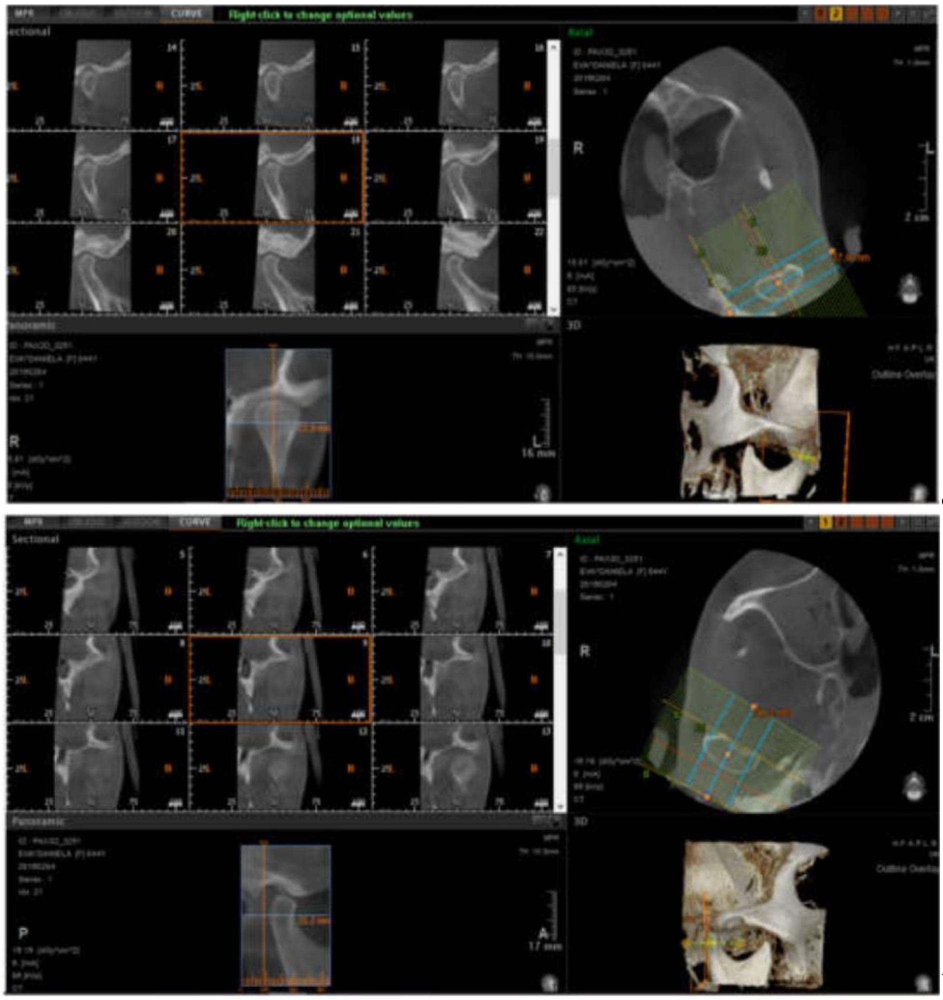
However, the difference was significant only for the condylar erosions in patients with SSc compared with control (18.60%, n = 8 vs. 232%, n = 1; $p < 0.05$). It may be only because the changes in the condyles are easier to detect compared to the others, especially in the early stages. In addition, changes due to stomatognathic system dysfunction (malocclusion, edentulism, maxillo-mandibular malrelationship) may also be superimposed.

f. Associations with PDL Space Widening and Erosions

Subgroup analysis in scleroderma subjects with and without PDL widening and with and without erosions based on univariate analysis including clinical parameters and oral radiographic abnormalities were, further, done (Table 8).

Significant correlations between number of teeth with PDL widening and MEDSGER disease severity score ($r = 0.702$, $p = 0.028$), RODNAN skin score ($r = 0.821$, $p = 0.01$), disease subset (diffuse vs. limited, $r = 0.782$, $p = 0.041$ vs. $r = 0.451$, $p = 0.05$, respectively), anti-topoisomerase I antibodies ($r = 0.568$, $p = 0.012$), age ($r = 0.872$, $p = 0.01$), and disease duration ($r = 0.811$, $p = 0.01$) were demonstrated.

Moreover, the relative risk of PDL space widening in relation with different determinants of scleroderma severity are listed in Table 9.



a

b

Fig. 8. CBCT aspects of the (a) right and (b) left TMJ.

Fig. 9. CBCT-condylar lysis and condylar remodeling.

For multivariate analysis adjusting for age, disease duration, gender, and smoking status, there were a significant association between the number of teeth with widened PLD and MEDSGER disease severity ($p < 0.05$) (Table 10).

Erosions were predominantly found in patients with aggressive scleroderma, especially related to the attachment of lateral pterygoids at the condylar head and masseter muscle at the angle of mandibula. Total resorption of the condylar head was reported only in one case (Fig. 9).

Also, there was an inverse association between interdental distance and the number of erosions (RR 3.51, 95% CI 1.67–2.95, p < 0.05) (Table 9).

Table 9. Associations between the number of teeth with PDL space widening and SSc severity.

Parameter	RR	95% CI
Gender	2.17	0.91–14.28
Age	1.00 *	0.89–1.73
Smoking status	5.31	4.27–9.12
SSc duration	3.26 *	1.20–7.53
SSc subtype	4.51 *	2.39–8.14
RODNAN skin score	0.93 *	0.89–3.76
SSc severity	1.25 *	1.58–3.89
SSc activity	2.36	1.02–3.41
Anti–topoisomerase 1	5.22 *	2.3–7.67

RR, relative risk; 95% CI. 595% confidence interval; * $p < 0.05$.

Table 10. Correlations between the number of teeth with PDL space widening and number of teeth with periodontal disease.

Parameter	RR	95% CI
Gender	2.17	0.91–14.28
Age	1.00	0.89–1.73
Smoking status	5.31	4.27–9.12
SSc duration	3.26 *	1.20–7.53
SSc subtype	4.51*	2.39–8.14
RODNAN skin score	0.93 *	0.89–3.76
SSc severity	1.25 *	1.58–3.89
SSc activity	2.32	1.45–3.22
Anti-topoisomerase 1	5.19 *	2.24–7.32
Number of teeth with periodontal disease	1.19	0.87–1.45

* $p < 0.05$.

Discussion

We performed a systematic 3-D analysis of the radiographic orofacial abnormalities associated with SSc, aiming to describe specific CBCT findings and to identify potential correlations with disease characteristics, activity/severity, or prognostic factors. This was a case–control study within an EUSTAR SSc-cohort and matching controls focused on a comprehensive evaluation of periodontal ligament and erosions as the most common radiographic manifestations in scleroderma. We reported an increased rate of PDL space widening with a tendency for significantly more teeth with widened PDL space in scleroderma as compared to controls irrespective of the evaluation method (number of teeth with abnormal PDL or individual evaluation per one tooth): 46.51% SSc with PDL widening in at least one tooth vs. 13.95% controls. Moreover, wider PDL space was generally detected in the posterior teeth in more than one quadrant, although anterior region was also involved.

Our results are within the range of reported data in literature by using conventional panoramic radiographs (38–66%) [67-70, 73, 143-146].

A systematic review of the literature addressing the impact of scleroderma on oral health has identified only a few studies having as endpoint the radiographic findings; moreover, the majority considered bi-dimensional panoramic radiographic assessment, and none of them focused on interrelations between imaging parameters and disease characteristic [62, 67-70, 73, 143-145].

A closer look to the Canadian Systemic Sclerosis Oral Health Study offered a relevant picture of oral manifestations related to SSc; this was an ambitious study focused on SSc interferences with oral conditions within a large cohort of patients selected from several rheumatology centers. Compared with controls, patients with SSc are significantly more likely to have more teeth (molars and premolars) with PDL space widening as well as mandibular erosions. Furthermore, the evaluation of radiographs by two blinded experts increased accuracy of the results [67-70].

We performed a panoramic approach of oral SS-related features by two-dimensional radiographs and also by high-resolution volumetric CBCT. Although the oral pattern of involvement in scleroderma on standard films is widely recognized, data on 3-D assessments are scare. In fact, only one study with a comparable design is still ongoing in a French cohort aiming to characterize precisely the oral manifestations associated with SSc and to identify specific radiological (3-D CBCT), clinical, and/or biological signs [147]. We used Adobe Photoshop for PDL space widening assessment on panoramic images; compared to the Canadian SSc Oral Health Study, where results were analyzed by two radiologists, in our study, data were read by only one radiologist, and this may have a potential bias for the accuracy of the results [67-70].

PDL remains an active tissue, with an increased remodeling capacity [67-69]. Widening of the PDL space may be related to SSc as a result of excessive and extensive fibrosis of the ligament correlating with disease severity [54, 60] and also may develop in occlusal/orthodontic trauma, periodontal/periapical disease, pulpo-periapical lesions, bisphosphonate-related jaw osteonecrosis, malignancies (osteosarcoma, chondrosarcoma, and non-Hodgkin lymphoma) or in radiation-induced bone defect [72]. In dental occlusion trauma, PDL involvement is usually related to excessive or para-axial biting forces and is generalized or located and associated with angular bone defects and teeth mobility, while in malignancies, PDL space widening is limited to the adjacent teeth and the lamina dura is involved. In contrast, in patients with scleroderma, the lamina dura frequently remains intact and a uniform enlarged PDL space occurs in more than one quadrant, usually in the posterior teeth [64-69, 71, 72].

On the other hand, we reported an increased frequency of mandibular erosions in about one out of four SSc (23.25%), particularly condylar erosions developed in the area of the lateral pterygoids muscle attachment to the bone (see figure). Our results are within the range reported from previous 2-D studies (7–10%); in fact, only one paper described a higher prevalence of mandibular angle involvement (83.33% cases) [67-70, 148, 149]. However, the difference was significant only for the condylar erosions in patients with SSc compared with controls ($p < 0.05$).

It is well established that mandibular findings in scleroderma include resorption of the angle, condyle, coronoid process, ascending ramus, and antegonial notch. However, complete condylar osteolysis and secondary mandibular resorption are only rarely documented [67-70, 144]. Abnormal muscle contraction with subsequent abnormal pressure on the bone via atrophic muscles at their attachment site [67-69, 145], bone ischemia due to vasculitis and deposition of collagen in vascular wall, as well as rigidity and pressure from overlying skin are among the mechanisms likely involved in the emerge and persistence of bone erosions in SSc [67-69, 144].

Calcifications within the periodontal ligament were not found in our study. An interesting paper published several years ago reported calcifications within the PDL space of most maxillary teeth seen on 3-D CBCT analysis as well as pulp calcifications in some incisors and premolars with subsequent root canal obliterations [146].

Finally, we investigated associations between SSc-related variables and typical oral radiographic features in scleroderma. To our knowledge, only the Canadian Oral Health Study has systematically assessed and reported such correlations; our analysis supports data already published, considerably increasing the expertise in oral health in different scleroderma settings. Interestingly, widening of the PDL space is related to disease severity, reflecting extensive fibrosis and aberrant collagen turnover, and no association with periodontal disease measures and missing teeth were described.

However, we did not observe any correlation between PDL space widening and smoking as previously described, although the influence of nicotine on fibroblast phenotype and activity within PDL space is recognized [67-70].

We described a significant negative correlation of mandibular erosions and interincisal distance, suggesting that abnormal local intraoral stress may be responsible for bone lesions; in addition, there was no relation with disease activity and severity. Condylar erosions were associated with clinical signs and symptoms of TMJ involvement, but this was not valuable for erosions with other location.

Our study has some limitations, e.g., the number of recruited patients, the evaluation of radiographs by only one expert, and associated multiple oral pathologies.

The quality of the images obtained is of paramount importance. There is a greater probability of correctly identifying and measuring fine structures like lamina dura and PDL when the image is acquired using the smallest voxel resolution parameters. On the other hand, a compromise has to be made in order to reduce patient exposure to X-rays by a shorter scanning time, using protocols that offer the same performances. In our study, the 0.4 mm voxel size was used for TMJ images, allowing a qualitative analysis, and 0.12 mm voxel size was used for PDL space measurements, allowing a quantitative evaluation.

Conclusions

To conclude, volumetric CBCT performance in assessing PDL space widening and mandibular erosions in patients with SSc shows promising results. Furthermore, PDL space widening as well as mandibular erosions are commonly reported in scleroderma and correlated with different disease characteristics especially severity, skin extent, and antibody profile. Future studies could investigate the pattern of PDL widening at different root heights and in different oral disease context.

2.1.2.3. Efficacy of baricitinib on periodontal inflammation in patients with rheumatoid arthritis

Aim of the study

The aim of this study was to evaluate the influence of baricitinib on periodontal health in patients with RA and to describe the inter-play between clinical, biologic and serologic RA characteristics and periodontal status.

Materials and method

We performed a prospective longitudinal study in twenty-one RA patients starting baricitinib for their moderate-to-severe active disease, followed-up in one academic rheumatology department in North-East Romania. Baricitinib was prescribed according to local recommendation for biologic and targeted synthetic therapy aligned with European League Against Rheumatism (EULAR) guidelines; before the study, patients presented inadequate response or intolerance to conventional synthetic antirheumatic drugs (cs D-MARDS) or biologics.

A dual rheumatologic and full mouth assessment was performed before starting baricitinib and reassessed after 24 weeks.

RA-related variables comprised disease activity based onDAS28-CRP (Disease Activity Score on 28 evaluable joints using C-reactive protein) and SDAI (Simplified Disease Activity Index), and serological markers (rheumatoid factor, RF, and ACPA).

Periodontal status was clinically evaluated using the number of teeth, full mouth plaque index (PI), gingival index (GI) and bleeding on probing (BOP) for the assessment of gingivitis, probing pocket depth (PD) and clinical attachment level (CAL) for current periodontitis and cumulative periodontal disease, respectively. Measurements of PD and CAL were performed with a Williams probe at four sites around each tooth and recorded to the nearest millimeter, every data close to 0.5 mm being rounded to the lower whole number. PI and BOP were reported as percentage (positive sites: all sites ratio). The missing and mobile teeth were clinically assessed and alveolar bone loss was measured on panoramic dental X-ray.

Case definitions for gingivitis and periodontitis as well as severity classifications were used according the new 2017 classification criteria [150]: level 1 (mild) – CAL ≥3 mm in ≥2 nonadjacent teeth and level 2 (severe) – CLA ≥ 5 mm in ≥30% of teeth; we considered level 0 – healthy periodontal status or up to one proximal site with CAL ≥3 mm.

Patients were instructed to maintain their oral hygiene habits the entire follow-up; any aggressive periodontal treatment (professional scaling, root planning) was avoided as we anticipated to evaluate the true impact of baricitinib on periodontal health.

As multiple confounders may interfere with correct interpretation of periodontal status [150], we excluded ex- or current smokers, patients with diabetes, patients receiving antibiotics or periodontal treatment within the previous 3 months, as well as patients having fewer than eight evaluable teeth.

Statistical analysis

Results were expressed as median and interquartile range 25–75% (IQR 25–75) or number (%), correlations by Spearman rank tests, while comparisons between baseline and 6 months of baricitinib were performed by Wilcoxon test. Statistics were done with SPSS software (version 19), P-values less than 0.05 being considered as statistically significant. The study protocol was approved by the local ethics committee and patients provided a written informed consent before their enrolment.

Results

Baseline RA and periodontal assessments

Demographics, rheumatologic and periodontal parameters as well as concomitant RA medication including glucocorticoids and DMARDs at baseline are summarized in Table 11 and Table 12.

We enrolled mainly seropositive longstanding RA, with moderate-to-severe active disease insufficiently controlled by cs D-MARDs or failing to respond to at least one biologic.

We described impaired oral health in the majority of patients (n = 19), as follows: 15 had fewer teeth than normal for age and gender-matches healthy controls, 9 gingivitis (abnormal GI and increased prevalence of sites with BOP), and 19 patients had different degrees of chronic periodontitis (level 1 + 2). Furthermore, advanced loss of attachment was reported in one out of five patients, while increased prevalence of sites containing dental plaques in 9 cases.

Subgroup analysis showed higher biological (CRP, ESR) and serologic (ACPA but not RF) activity in patients with severe, either localized or generalized, periodontitis, compared to RA patients without periodontitis ($P < 0.05$). In addition, significant direct association was demonstrated between the periodontitis level, RA activity and ACPA levels (r1= 0.78, p1= 0.001, r2= 0.76, p2= 0.002, respectively): patients with more active RA and higher ACPA had more severe periodontitis (tooth loss, advanced CAL, severe PD).

Table 11. Demographic and rheumatologic characteristics of RA patients before and after baricitinib therapy.

Characteristics	Baseline	24 months	*P*-values*
Gender (female/male)	18/3		
Age (years)	60.00 [53.25–64.5]		
RA duration (months)	117.16 [49.25–159.00]		
Concomitant medication			
Corticosteroids (*n*)	6		
Methotrexate (*n*)	13		
Leflunomide (*n*)	4		
Antimalarials (*n*)	2		
Without DMARDs (*n*)	2		
Previous biologics			
Bio-naïve RA/bio-experienced RA (*n*)	3/18		
Serology	17		
RF positive (*n*)	265.9 [128.5–321.2]	202.3 [127.1–272.5]	
RF titer (IU/mL)	12		0.27
ACPA positive (*n*)	321.17 [89.3–441.2]	175.67 [58.2–201.3]	**0.01***
ACPA titer (IU/mL)			
Inflammation			
CRP (mg/dL)	4.61 [3.60–7.99]	2.57 [1.49–3.2]	**0.02***
ESR (mm/hour)	48.63 [38.50–55.50]	25.00 [23.25–32.75]	**0.01***
Disease activity			
DAS28-CRP	5.53 [4.91–6.00]	3.97[3.74–4.37]	**0.02***
SDAI	21.00 [18.18–27.38]	11.5 [10.00–13.75]	**0.01***

RA: rheumatoid arthritis; DMARDs: Disease-Modifying AntiRheumatic Drugs; RF: rheumatoid factor; ACPA: anti-citrullinated peptide antibody; ESR: erythrocyte sedimentation rate; CRP: C-reactive protein; DAS28-CRP: Disease Activity Score including 28 joints using C-reactive protein; SDAI: Simplified Disease Activity Index; (n): number of patients; all data are presented as median and IQR values [25%–75%]; the bold values show the statistical significance.
**Significantly different from the baseline, as assessed by Friedman and Wilcoxon signed rank tests ($P < 0.05$).*

Table 12. Periodontal status in RA patients before and after oral baricitinib

Parameter	Baseline	24 months	*P*-values
Teeth count (*n*)	22.00 [20.25–23.75]	22.00 [20.25–22.75]	NS
% sites with plaque	31.00 [29.25–33.75]	30.00 [28.25–31.75]	NS
GI	0.98 [0.95–1.10]	0.82 [0.80–0.86]	$P<0.05$
% sites with BOP	11.15 [10.12–12.10]	7.00 [6.50–8.1]	$P<0.05$
PD (mm)	2.85 [2.80–2.90]	2.00 [1.90–2.20]	$P<0.05$
% sites with PD ≥ 4 mm	12.7 (2.4)	8.3 (2.9)	$P<0.05$
CAL (mm)	3.4 [3.1–3.7]	3.00 [2.9–3.2]	NS
% sites with CAL ≥ 4 mm	12.5 [11.05–13.0]	12.00 [11.05–12.25]	NS

Values are indicated as % or median [1st and 3rd quartiles]. RA: rheumatoid arthritis; GI: gingival index; BOP: bleeding on probing; PD: probing depth; CAL: clinical attachment level; NS: not significant ($P > 0.05$).

Effects of baricitinib on rheumatologic and periodontal parameters

Modifications in the periodontal status, clinical and biological RA activity were reassessed after 24 weeks, looking for the benefits of baricitinib.

As expected, all RA parameters significantly decreased; DAS28-CRP and SDAI strongly improved reaching moderate-to-low values, with a change of more than 1.2 points (EULAR-responders) vs. baseline, irrespective of the presence and severity of periodontitis. However, there was a trend to better improve in RA with periodontitis, although not significantly. Similarly, we reported a consistent decline in inflammation markers (both ESR and CRP), as well as a considerable immunologic response, particularly for ACPA levels, but also for RF (Table 11).

Patients with chronic periodontitis showed also a significant decrease in periodontal inflammation as suggested by improved GI, sites with BOP, PD and sites with PD ≥ 4 mm vs. baseline ($P < 0.05$) (Table 12). Overall, clinical attachment level presented only slight changes without statistical significance; teeth count and bacterial plaque were also not significantly influenced by medication ($P > 0.05$) (Table 12).

Changes (Δ) in periodontal parameters after short-term baricitinib were calculated: significant change in PD −0.8[0.7–0.9]and Δ % sites with PD≥ 4 mm −3.5 [2.25–5] together with significant modifications in GI −0.15[0.13–0.28] and sites with BOP −3.8[3.2–4.95]; nevertheless, we showed only minor changes in periodontal parameters such as Δ CAL 0.3[0.4–0.5] and %sites with CAL ≥ 4 −0.6[0.2–0.97] as well as gingival plaque and %of sites with gingival plaques ($P > 0.05$).

No significant correlations between variation of periodontal parameters with variation of RA were described ($P > 0.05$).

Since local periodontal treatment was not indicated during the short−term follow−up, we considered that improvement in all parameters investigating the degree of local gingival and periodontal inflammation is related to JAK blockade.

Discussion

We performed this study aiming to evaluate the influence of tsDMARDs on periodontal health in RA patients; we assumed that baricitinib, a JAK inhibitor blocking the subtypes JAK1 and JAK2, might decrease the levels of pro-inflammatory mediators in the periodontal microenvironment via the decline in systemic inflammation.

Before emphasizing the benefits of baricitinib on periodontal condition, we focused on oral health status in our RA cohort.

Firstly, we confirmed compromised oral health in the majority of cases, particularly a high rate of moderate-to-severe periodontal disease, confirming the already known risk of periodontitis in established RA [79, 80, 83, 87, 108]. Although we discussed only about longstanding RA, several other studies have already noticed excessive periodontal disease nevertheless of RA settings (age, disease duration, serology profile, activity) vs. general population [79, 80, 86, 87]. We identified abnormal periodontal parameters (increased PD, CAL) as well as high levels of gingival involvement confirmed by increased percentage of sites with plaques and inflammation, supporting data from literature [78, 79]. Moreover, we recognized positive correlations between the severity of periodontitis, inflammatory parameters (especially CRP), serology (ACPA status and titres) and RA activity; indeed, recent studies suggest worst periodontal status in active untreated RA, and higher CRP if RA is associated with severe periodontitis [78-80, 86, 87]. Finally, it seems that ACPA-positive patients had severely impaired periodontal health, while disease activity correlated with periodontitis degree as well [79-81, 86-88].

Secondly, we registered a rapid and consistent response to baricitinib, regardless of patient's previous medication (bio-naïve or bio-experienced RA); short-term JAK inhibition can result in significant improvement in clinical, biologic and, surprisingly, serologic RA activity (especially for ACPA, and here one can comment about the implications via citrullination at the periodontal and synovial microenvironment). Our results reasonably confirm the efficacy of baricitinib in controlling inflammation pathways in active established RA [98].

Thirdly, short-term course of baricitinib significantly reduced gingival and periodontal inflammation as suggested by improvement in GI, BOP, PD, paralleling the articular improvement. However, only minor changes in CAL were noticed, while the bacterial PI remained stable after 24 weeks of baricitinib ($P > 0.05$). That means a positive reaction of gingiva related to baricitinib, even though bacterial plaque index remained the same; that is really encouraging.

All patients continued background medication, their dental hygiene behaviour remained unchanged, and no periodontal therapy was practiced; accordingly, we concluded that the decrease in GI and BOP might be related to decrease in gingival inflammation induced by baricitinib.

Recent reports offer suitable arguments to reinforce that early aggressive RA management with csDMARDs and/or biologics not only promote sustained remission, but also impact periodontal damage [78, 79, 90, 91, 98]. It seems that regular treatment with biologics or non-biologics may retrieve periodontal status in RA with periodontitis [78, 79, 92-97]. Additionally, innovative biologics acting by blocking the TNF and IL-6-mediated signalling are also able to promote reliable decrease in inflammatory cytokines and antibodies with dramatic effect not only on clinical, biological and serological activity of RA, but also on oral health [84, 90, 91, 93-97].

A closer look for evidences concerning TNF inhibitors in improving chronic periodontitis showed inconsistent results [78, 79, 84, 93-97]. Several papers clearly demonstrated the efficacy of TNF blockade in controlling both RA and periodontitis [84, 92-97], but others recognized only uncertain advantages unless concomitant specific periodontal treatment, even surgical procedures [96]. Interestingly, it seems that infliximab, a monoclonal antibody targeting TNF, enhances gingival inflammation, while improving alveolar bone destruction [78, 79, 105]; besides, infliximab dissociates response of severe periodontal destruction biomarkers (e.g. matrix metalloproteinase 3) in RA [105]. In contrast, both tocilizumab and rituximab promote a significant down regulation of gingival inflammation and gingival damage in RA associated with periodontitis related to decrease in serum inflammatory mediators [92, 94].

The influence of intensive periodontal treatment on RA is similarly controversial. Several publications [131, 133-135] have successfully demonstrated that specific therapies for chronic periodontitis (e.g. non-surgical professional scaling or root planning with or without antibiotics) may ameliorate local inflammation, improve RA activity and response to different anti-rheumatic drugs. However, other reports [133] fail to demonstrate successful RA outcomes with periodontal treatment; indeed, ESPERA trial emphasized improved periodontal health with periodontal treatment in RA, but no effect on clinical parameters assessed by DAS28 [133].

Data about JAK inhibitors in periodontitis are scarce; only one recent publication already mentioned the role of tofacitinib in two cases of RA and comorbid periodontal disease [150]. As suggested, efficacy of tofacitinib seems to be related to the suppression of systemic inflammation promoted by high levels of IL-6 through a sustained inhibition of IL-6 signalling [150]. Unfortunately, the level of IL-6 or its receptor in gingival crevicular fluid was not assessed, although serum concentration showed a significant and rapid decline.

Conclusions

Our main results are focused on baricitinib efficacy for joint and periodontal disease as well. In short-term we registered a significant decrease in clinical, biologic and serologic RA activity; we also noticed improvement of periodontal condition especially related to decrease in gingival inflammation (as supported by decreased in gingival index, bleeding on probing, sites with bleeding), but also on probing depth. That means a positive reaction of gingiva related to baricitinib, despite the fact that bacterial plaque index remained the same.

However, we failed to describe any significant correlations between variation of periodontal and rheumatologic parameters.

To the best of our knowledge, this is the first report to compare periodontal condition in patients with RA and chronic periodontitis before and after baricitinib therapy; our results showed beneficial effects of baricitinib on levels of periodontal inflammation, which might be related to inhibition of IL-6 and JAK-mediated cytokine signalling.

Further studies in larger number of RA patients and chronic periodontitis are necessary to confirm our results, with longer follow-ups and, eventually, with control group. Moreover, it would be interesting to explore cytokine level in gingival crevicular fluid and the influence of oral baricitinib.

2.1.2.4. Exploring the role of interleukin-6 receptor inhibitor tocilizumab in patients with active rheumatoid arthritis and periodontal disease

Aim of the study

Considering the gap in the literature regarding the role of anti-rheumatic drugs on periodontal outcomes, the aim of our study is to assess the influence on the periodontal status of weekly subcutaneous administration of tocilizumab in a local group of patients with rheumatoid arthritis and chronic periodontitis.

Materials and method

a. Study Design and Population

We performed a prospective longitudinal study in fifty-one patients with moderate-to severe RA and insufficient response to either conventional synthetic or biologic disease modifying antirheumatic drugs (DMARDs), starting TCZ according to the local recommendation for biologic and targeted synthetic therapy aligned with European League Against Rheumatism (EULAR) consensus statement and guidelines.

We performed extensive rheumatologic and full mouth assessments at baseline (before the first administration of TCZ) as well as after 3 and 6 months of therapy.

b. Inclusion Criteria

The patients were aged 18 and older, able to give informed consent themselves and to participate in the study, and willing to forgo any optional examinations. Patients fulfilled either the old 1987 American College of Rheumatology (ACR) criteria or the new 2010 classification criteria of ACR and EULAR and were followed up in one academic rheumatology department in Northeast Romania over a period of 3 years (July 2017–January 2020).

c. Exclusion Criteria

Several exclusion criteria were applied before enrollment in this study because of their potential interference with a correct evaluation of periodontal status, as follows: exor current smokers, pregnant and breastfeeding women, patients with diabetes mellitus, implants, poorly fitting fixed and/or removable prosthodontics and fewer than eight evaluable teeth, patients receiving systemic or local antimicrobials, antiplatelet drugs, any type of anti-inflammatory medication or periodontal therapy within the previous 3 months.

A total of sixty-eight patients were eligible for and received TCZ for their active RA; however, among them, seventeen had no oral issues at baseline evaluation and were excluded from the study.

d. Ethical Considerations

The baseline clinical documentation of periodontitis cases was collected in the context of routine check-up in the dental clinic of Sanocare Medical and Research Center.

The study was approved by the local ethics committee (Sanocare Medical and Research Center, Prot. No 15/12.12.2016) and was found to conform to the guidelines of the Declaration of Helsinki. Written informed consent regarding the use of the collected data in the context of training and research was signed by all the participants before enrollment. The data used in the study were anonymized. According to the U.S. Department of Health and Human Services (HHS) definition, this investigation is not considered human subjects research.

e. Rheumatologic Assessments

RA-related variables comprised clinical (tender and swollen joint count based on a 28-joint assessment, 0–10 cm visual analogue scale, VAS, pain), inflammatory tests (erythrocyte sedimentation rate, ESR, and C-reactive protein, CRP) as well as disease activity scores calculated on DAS28-CRP (Disease Activity Score on 28 joints using C reactive protein) and SDAI (Simplified Disease Activity Index) were performed at all three visits.

DAS28-CRP was calculated with a formula that considered the tender and swollen joints, the patient's general assessment of their condition scored on a visual analogue scale (VAS), and CRP. DAS28-CRP comprises four categories: remission (DAS28-CRP < 2.3), low ($2.3 \leq$ DAS28-CRP < 2.7), moderate ($2.7 \leq$ DAS28-CRP < 4.1), and high disease activity ($4.1 \leq$ DAS28-CRP).

Designed as the numerical sum of five outcome parameters (tender and swollen joints, patient, and physician global assessment of disease activity on a 0 - 10 VAS and CRP level), SDAI score interpretation comprises also four categories: remission (0 - 3.3), low activity (3.4 - 11), moderate activity (11.1 - 26), and high RA activity (26.1 - 86). Serological biomarkers (rheumatoid factor, RF, and ACPA) were evaluated only at baseline.

f. Periodontal Assessments

The periodontal status was recorded on a periodontal chart displaying the following clinical parameters for the entire dentition: number of present teeth, visible plaque index (VPI), gingival index (GI), bleeding on probing (BOP), probing pocket depth (PPD), and clinical attachment loss (CAL).

Clinical periodontal assessments were performed by a single trained examiner (C.I.) at the Sanocare Medical and Research Center, Iasi, who was blinded to the rheumatologic data.

Access to previous assessment data was not allowed during the study. The examiner was considered calibrated when no statistically significant differences between measurements were obtained after the evaluation of 15 non-participant subjects on two occasions, one week apart. The mean values were assessed using paired t-test for VPI, GI, BOP, PPD, and CAL.

The periodontal evaluation was made in artificial light conditions, using a dental explorer, dental mirror, Williams probe, and air–water syringe.

VPI [151] or supragingival plaque was recorded dichotomously (present/absent) at 4 sites (mesial, distal, buccal, lingual/palatal) around each tooth. GI [152] assesses the gingival condition by gentle probing of the soft gingival wall at four sites for each tooth, as follows: 0 = absence of inflammation; 1 = mild inflammation: slight changes in color and texture, and slight edema, no bleeding on probing; 2 = moderate inflammation: redness, edema, glazing, bleeding on probing; 3 = severe inflammation: marked redness, edema, ulceration, tendency to spontaneous bleeding.

BOP evaluates gingival inflammation through bleeding observed 20 s after a probe is passed along inside the gingival sulcus or pocket. It was recorded dichotomously (present/absent) at 6 sites (mesiobuccal, mid-buccal, distobuccal, mesiolingual, mid-lingual, and distolingual) around each tooth.

PPD was measured between the gingival margin and the bottom of gingival sulcus or pocket, while CAL was measured between the cement–enamel junction and the base of the gingival sulcus or pocket. Both parameters were determined with Williams periodontal probe and recorded on 6 sites per tooth. The recorded values were to the nearest millimeter, and every reading close to 0.5 mm was rounded to the nearest integer number.

PD was considered according to the case definition proposed by the 5th European Workshop on Periodontology in 2005 [153], as follows: level 1 (mild) - AL ≥ 3 mm in 2 or more proximal sites of non-adjacent teeth and level 2 (severe) - CAL ≥ 5 mm in 30% or more proximal sites of teeth present; level 0 was considered - for healthy periodontal status or up to one proximal site with CAL ≥ 3 mm.

Patients were instructed to maintain their oral hygiene habits throughout the 6 months of follow-up; furthermore, as we intended to assess the accurate effect of TCZ on periodontal status, any periodontal treatment was avoided.

g. Statistical Analysis

Statistical analysis was performed with the IBM SPSS Statistics for Windows, Version 19.0. (IBM Corp., Armonk, NY, USA), with p-values less than 0.05 being considered as statistically significant; data at 3 and 6 months were summarized as means ± SD, or percentages (%) as appropriate, and correlations by Spearman rank tests; comparisons between baseline and 3 and 6 months of TCZ were assessed by Wilcoxon test.

Results

Baseline RA and Periodontal Assessments

Demographics, rheumatologic and periodontal characteristics, as well as RA-related drugs (concomitant glucocorticoids and immunosuppressives) taken at baseline are summarized in Table 13.

Most patients included in our study had seropositive established RA, with moderate to-severe activity despite background medication. Eight patients (15.68%) received TCZ as their first biologic agent (bio-naïve), while the majority were bio-experienced patients, with failure (either insufficient response or adverse reactions) to previous biologics - 15 (29.41%) to one biologic, 20 (39.21%) to two biologics, and 8 (15.68%) to three biologic agents.

We detected impaired oral health in all patients included in the final analysis, as follows: all had gingivitis (abnormal GI and increased prevalence of sites with BOP), and different degrees of chronic periodontitis (mainly level 1 and 2); advanced loss of attachment was reported in up to 23.52% of cases, while increased prevalence of sites with dental plaques in 21.56% of cases.

A closer look revealed a consistent positive correlation between the severity of chronic periodontitis, RA activity, and serum $r2 = 0.71$ ACPA concentrations ($r1 = 0.81$, $p1 = 0.001$, $p2 = 0.002$, respectively): the higher the RA activity and ACPA levels, the higher the PPD severity, with advanced CAL and tooth loss.

Changes in Rheumatologic and Periodontal Parameters with Tocilizumab

Changes in RA activity and periodontal status were reassessed after 3 and 6 months of TCZ; at follow-up visits, we reported significant improvement as compared to baseline ($p < 0.05$), although the results at 6 months were only slightly different from data obtained at 3 months ($p > 0.05$).

a. Changes in Rheumatologic Status

Patients displayed consistent improvements in clinical activity meaning a significant decrease in the number of tender and swollen joints, VAS pain, and morning stiffness as rapid as 3 months; as expected, clinical response was maintained 3 months later in all patients, at the final monitoring visit. Similarly, we reported a dramatic decline in inflammatory biomarkers (both ESR and CRP), as well as a considerable immunologic response, particularly for serum levels of ACPA, but also for RF (Table 14).

Table 13. Demographic, rheumatologic, and periodontal characteristics at baseline

Demographics	
Age (years; mean ± SD)	56.3 ± 15.7
Female (*n*, %)	46 (90.1)
RA-related parameters	
Duration of RA (months; mean ± SD)	81.3 ± 68.9
DAS28-CRP (mean ± SD)	5.36 ± 1.67
SDAI (mean ± SD)	34.2 ± 16.3
Corticosteroids (*n*, %)	20 (39.21)
DMARDs (*n*, %)	46 (90.1)
ACPA levels (U/mL; mean ± SD)	239.7 ± 124.3
ACPA positivity (*n*, %)	32 (62.74)
RF levels (IU/mL; mean ± SD)	192.7 ± 85.3
RF positivity (*n*, %)	47 (92.15)
Serum CRP levels (mg/dL; mean ± SD)	15.3 ± 6.9
PD-related parameters	
Number of present teeth (mean ± SD)	23.7 ± 3.4
GI (mean ± SD)	0.98 ± 0.12
% sites with plaque (mean ± SD)	32.4 ± 16.9
% sites with BOP (mean ± SD)	10.2 ± 8.6
PPD (mm; mean ± SD)	2.8 ± 0.4
% sites with PPD ≥ 4 mm	12.7 ± 2.5
CAL (mm)	3.5 ± 1.2
% CAL ≥ 3 mm	12.5 ± 0.2

RA, rheumatoid arthritis; DAS28-CRP, Disease Activity Score on 28 joints using C-reactive protein; SDAI, Simplified Disease Activity Index; DMARDs, disease-modifying antirheumatic drugs; ACPA, anti-citrullinated protein antibodies; RF, rheumatoid factor; PD, periodontal disease; GI, gingival index; BOP, bleeding on probing; PPD, probing pocket depth; CAL, clinical attachment loss; n, number; SD, standard deviation; %, percent.

Table 14. Changes in rheumatoid arthritis (RA)-related parameters at 3 and 6 months after tocilizumab

Parameter	Baseline	3 Months (V1)	6 Months (V2)	*p*-Value
DAS28-CRP (mean ± SD)	5.36 ± 1.67	3.39 ± 0.57	2.41 ± 0.19	* <0.05; ** <0.05
SDAI (mean ± SD)	34.2 ± 16.3	18.1 ± 8.2	11.1 ± 4.3	* <0.05; ** <0.05
Number of tender joints (mean ± SD)	12.31 ± 4.29	4.56 ± 1.31	3.55 ± 1.13	* <0.05; ** NS
Number of swollen joints (mean ± SD)	10.01 ± 3.37	2.85 ± 4.22	1.50 ± 2.09	* <0.05; ** NS
Pain VAS mm (mean ± SD)	82.7 ± 21.5	28.8 ± 23.2	16.3 ± 11.8	* <0.05; ** <0.05
Serum anti-CCP titer (U/mL) (mean ± SD)	239.7 ± 124.3	192.6 ± 112.4	123.6 ± 101.6	* <0.05; ** NS
Serum RF levels (IU/mL) (mean ± SD)	192.7 ± 85.3	164.8 ± 92.5	151.7 ± 89.3	* NS; ** NS
Serum CRP levels (mg/dL) (mean ± SD)	15.3 ± 6.9	4.12 ± 0.92	3.92 ± 0.34	* <0.05; ** NS

SD; standard deviation; DAS28-CRP, Disease activity score on 28 joints based on C-reactive protein; SDAI, Simplified Disease Activity Index; VAS, 0–10 cm visual analogue scale; CCP, cyclic citrullinated peptide; RF, rheumatoid factor; V, visits; * V1 compared to baseline; ** V2 compared to V1; NS, non-significant (0.05).

a. Changes in Periodontal Status

Clinical data showed improvement in periodontal inflammation after only 3 months of TCZ and maintained over 6 months, as supported by an important decrease in gingival index and sites with bleeding of probing ($p < 0.05$). However, the improvement of specific periodontal parameters such as probing pocket depth becomes evident after prolonged treatment (6 months); overall, clinical attachment loss presented only slight changes without any statistical significance; teeth count and bacterial plaque scores were also not significantly influenced by medication ($p > 0.05$) (Table 15).

No significant correlations between changes in periodontal parameters and changes in RA activity were described in our study ($p > 0.05$).

We assumed that all the modifications in the degree of local gingival and periodontal inflammation is related to IL-6 blockade as no local periodontal treatment was allowed during follow-up.

Table 15. Changes in PD-related parameters at 3 and 6 months after tocilizumab

Parameter	Baseline	3 Months (V1)	6 Months (V2)	*p*-Value
DAS28-CRP (mean ± SD)	5.36 ± 1.67	3.39 ± 0.57	2.41 ± 0.19	* <0.05; ** <0.05
SDAI (mean ± SD)	34.2 ± 16.3	18.1 ± 8.2	11.1 ± 4.3	* <0.05; ** <0.05
Number of tender joints (mean ± SD)	12.31 ± 4.29	4.56 ± 1.31	3.55 ± 1.13	* <0.05; ** NS
Number of swollen joints (mean ± SD)	10.01 ± 3.37	2.85 ± 4.22	1.50 ± 2.09	* <0.05; ** NS
Pain VAS mm (mean ± SD)	82.7 ± 21.5	28.8 ± 23.2	16.3 ± 11.8	* <0.05; ** <0.05
Serum anti-CCP titer (U/mL) (mean ± SD)	239.7 ± 124.3	192.6 ± 112.4	123.6 ± 101.6	* <0.05; ** NS
Serum RF levels (IU/mL) (mean ± SD)	192.7 ± 85.3	164.8 ± 92.5	151.7 ± 89.3	* NS; ** NS
Serum CRP levels (mg/dL) (mean ± SD)	15.3 ± 6.9	4.12 ± 0.92	3.92 ± 0.34	* <0.05; ** NS

SD; standard deviation; DAS28-CRP, Disease activity score on 28 joints based on C-reactive protein; SDAI, Simplified Disease Activity Index; VAS, 0–10 cm visual analogue scale; CCP, cyclic citrullinated peptide; RF, rheumatoid factor; V, visits; * V1 compared to baseline; ** V2 compared to V1; NS, non-significant (0.05).

Discussion

We aimed to assess the influence of the IL-6 receptor inhibitor on periodontal status in active RA associated with periodontitis, assuming that TCZ might be able not only to improve clinical and biochemical RA-related parameters but also to ameliorate chronic periodontitis as a result of decreased IL-6 in the periodontal microenvironment via declining systemic inflammation.

Although our target is to demonstrate the ability of TCZ to modulate periodontal inflammation and subsequent damage, firstly, we emphasized its role in controlling RA activity. We reasonably confirmed a consistent response to TCZ in real-life settings, which was achieved in as rapid as three months and continued after six months of therapy, irrespective of background medication and clinical scenario (mono- or combined therapy, bio-naïve or bio-experienced patients); it is more than clear that even in the short-term, IL-6 blockade displays significant clinical, biological, as well as serologic disease improvement. Although we found no consistent difference in clinical response in seropositive vs. seronegative RA, we noticed a significant impact on ACPA serum concentration after six months, which is an improvement that parallels the decrease in periodontal inflammation, suggesting a role of IL-6 in both systemic and local inflammation (synovial and periodontal) and the potential implications via citrullination. Therefore, our results stand by as a proof of the effectiveness of subcutaneous TCZ in managing inflammatory and immune pathways in RA [135].

We also focused on the magnitude of compromised oral health in RA; most patients in our initial group presented a high rate of mild and severe periodontal disease, validating/reinforcing the already known risk of periodontitis in such patients, particularly in established, longstanding disease [101-104, 123]. We have included in the final analysis only those cases with overt periodontal disease, meaning that up to 75% had at baseline altered periodontal status in a group of consecutive patients starting TCZ for their active disease.

Indeed, recent reviews and meta-analyses have already discussed periodontal disease in various RA settings (independent of age, disease duration, serology profile, and disease activity) compared to general population [79, 83, 87, 100, 102, 105, 112, 113].

We identified excessive gingival involvement confirmed by an increased percentage of sites with plaques and inflammation and abnormal periodontal status (e.g., increased probing depth, clinical attachment loss) supporting data from the literature [81, 84, 90, 91, 94, 95, 107, 112, 113, 116, 128]. Moreover, we recognized positive correlations between the severity of periodontitis, inflammatory parameters (especially CRP), serology (ACPA status and titers), and RA activity; indeed, recent studies suggest a worse periodontal status in active untreated RA, and higher CRP if RA is associated with severe periodontitis [79, 81, 86, 87, 94, 107, 116, 123]. Finally, it seems that ACPA-positive patients had severely impaired periodontal health, while disease activity correlated with periodontitis degree as well [79, 81, 94, 107, 116, 123].

Finally, we demonstrated that short-term tocilizumab significantly reduced gingival as well as periodontal inflammation as supported by decreased levels of gingival index, bleeding on probing, and probing pocket depth, paralleling the articular improvement. Indeed, only minor changes in clinical attachment loss were detected in our enrolled patients, and the supragingival plaque remained stable after 3 and 6 months of biological treatment ($p > 0.05$).

A closer look at recent data definitely emphasizes the dual effects of early and aggressive RA treatment with biologic and non-biologic drugs (Janus kinase inhibitors, JAK inhibitors) on articular as well as comorbid periodontal disease [80, 84, 91, 94, 105, 107, 110, 115, 116, 123, 146].

It is widely accepted that TNF and IL-6 receptor inhibitors are able to ameliorate oral health in active RA, as reflected by clinical, biological, and even serological RA biomarkers [84, 90, 91, 94-96, 105, 107, 116, 127]. Although there are controversial effectiveness signals with TNF inhibitors in improving chronic periodontitis [79, 81-83, 86-88, 90, 91, 102, 115, 120], all papers about anti-IL-6 therapy clearly demonstrated articular, systemic, and also periodontal benefits with TCZ without any periodontal specific treatment [84, 94, 107, 116].

An interesting trial compared periodontal condition in patients with RA and periodontitis before and after biological therapy in two cohorts: one under tocilizumab and the other receiving medication with TNF inhibitors [84]. After 6 months, both tocilizumab and TNF inhibitors demonstrated a consistent improvement of oral health with significantly reduced periodontal inflammation (gingival index, bleeding on probing, and probing depth) compared to baseline, with similar results in both cohorts unless there was a greater decrease in gingival index and less gingival inflammation with tocilizumab; however, plaque levels remained the same irrespective of medication, while periodontal clinical attachment loss decreased only after TCZ but not after TNF inhibitors [84, 94, 107, 116]. These observations were partially supported by the results of another study about an excessive inflammatory response against oral pathogens essentially based on high levels of IL-6 [84, 94, 107, 116, 129].

Recent meta-analyses reviewed the most important studies on TNF and non-TNF biologics in patients with RA and PD [105, 112]. The critical difference between the class of TNF inhibitors and TCZ or B-cell depletive agent rituximab is that infliximab, an anti-TNF monoclonal antibody, may negatively address gingival inflammation although it may also improve alveolar bone destruction [78, 79, 81, 105, 123] resulting in a dissociated response for patients with severe periodontitis [105], while both tocilizumab and rituximab associate with significant a down regulation of gingival inflammation and damage in RA associated with periodontitis [84, 92, 94, 107, 116].

Additional research is necessary to clearly differentiate between the direct effects of TCZ on local periodontal inflammation and IL-6 or its receptor levels in the gingival crevicular fluids and periodontium of patients and the indirect effect via dramatically decreasing systemic inflammation, which may impact also oral health [84, 94, 107, 116]. Indeed, numerous studies indicated a rapid and significant decline in typical inflammatory parameters (ESR and CRP), but also in serological RA biomarkers (RF, ACPA) as well as inflammatory cytokines (TNF, IL-6) and mediators (serum-amyloid A, matrix metalo-proteinases 1, 3), supporting the indirect role of TCZ in periodontitis [84, 94, 107, 116].

Conclusions

In our study, we assessed specific gingival and periodontal parameters before and after short-term TCZ therapy. We demonstrated successful RA as well as periodontal outcomes with TCZ and independent of potential confounding factors (such as smoking, diabetes, hematological conditions, sex steroid hormones elevations, pharmacological agents) related to periodontal disease, as such patients were excluded from the final analysis.

We concluded that tocilizumab decreased gingival inflammation since no periodontal therapy was permitted and the dental hygiene behavior remained unchanged in our enrolled patients.

Unfortunately, we were not able to assess either the serum or gingival crevicular fluid levels of IL-6 or its receptor in all patients; we assumed that tocilizumab indirectly contributes to modulate local (gingival and periodontal) inflammation by limiting systemic inflammation. Indeed, the biofilm plaque accumulation was not consistently diminished with tocilizumab, and we were not able to depict a spectacular impact on clinical attachment loss, but we arrived to demonstrate a positive effect of IL-6 blockade on exuberant gingival inflammation.

Further studies are necessary to confirm the benefits of Il-6 inhibitors in larger populations and longer follow-ups also focusing on IL-6/IL-6 receptor levels in gingival crevicular fluid.

2.2. RESEARCH ON THE BIOMECHANICS OF DENTAL RESTORATIONS

The success of a dental restoration depends on reaching an equilibrium between the live natural structures and the artificial substitutes that come to fill in the substance defect. The biological and functional integration of these restorations becomes fundamental in the context of a wide diversity of clinical scenarios [154, 155]. In relation to these scenarios, numerous therapy options exist and both the talent and the competence of the practitioner are measured quite often by his/her ability to find the correct therapeutic solution, perhaps even more than by the impeccable implementation of this solution. This means that the physical skills and the perfect timing of the technological procedures are not a guarantee for success if the therapeutic solution was not correctly selected.

Biomechanical problems arise in the case of all dental restorations, regardless of their type, but particularly in the case of indirect ones, when it is necessary to highlight the biomechanical stresses to which each component is subjected: the restorations, the dental tissues on which the restorations are applied on and the supporting periodontal tissues.

Biomechanical balance implies the congruence between the biomechanical stability of dental restorations and the resistance of oral tissues. Along with the remnant teeth, the restoration will withstand the forces triggered by the masticatory muscles, during the mastication and the deglutition functions. The biomechanical principle aims to know the constraints in the dento-periodontal complex on one hand and, on the other hand, the configuration to be given to the dento-prosthetic structure, so that the restoration counteracts the stress in order to allow the system to be in a static and dynamic balance. To achieve a proper biomechanical equilibrium, it is necessary to provide a dento-periodontal support capable of coping with the active forces. The biomechanical value of the abutment teeth is influenced by a multitude of factors, including the degree of implantation in the alveolar bone. For the same reason, various materials have been introduced over time for improving the performance of the existing ones. Among these are the fiber-reinforced composite materials whose indications have been extended to the field of prosthetic restorations and periodontal splints.

Composite materials are defined as a combination of different heterogeneous materials having their own distinct and individual properties. This combination gains improved structural or functional properties not present in any individual component. This type of materials have been initially developed by the aerospace industry, beginning with 1960, to answer the necessity of improving the characteristics of materials in accordance with specific requirements and in a specific environment [156]. Thus, newer generation of aircraft contain in their structure up to 50% composite materials (e.g. Boeing – 787 Dreamliner). These materials offer, besides versatility, a much better strength-to-weight ratio compared to metals, sometimes even by as much as 20% [157]. With improved characteristics, these materials can be transferred to the oral environment which, in some aspects, seems to be even more hostile than the outer space. The first significant results in this field of research appeared in the early ’80s through the use of carbon fibre and especially aramid (Kevlar, DuPont, Wilmington, Delaware). They are not randomly oriented like short fibres, but carefully aligned to form a unidirectional tape [156].

Fibre-reinforced composites (FRCs) are composite materials with three different components: the matrix (continuous phase), the fibres (dispersed phase), and the zone in between, or interface (interphase) [158]. This last zone corresponds to the adhesive interface ideally created between the fibres within the composite matrix and the resin to which they are bonded. The matrix (polymerized monomers) holds the fibres together, transfers stresses between fibres and protects the fibres from outside environment [159]. The reinforcing component provides strength and stiffness, and the matrix supports the reinforcement and provides workability [160-164].

The mechanical characteristics and the effectiveness of the fibre reinforcement in FRC are based on fibre type (glass, polyethylene, carbon, aramid), quantity of fibres, fibre structure including unidirectional, bidirectional and randomly oriented fibre, fibre position [165], fibre-resin matrix adhesion, fibre and resin matrix properties, quality of fibre impregnation and water sorption of the FRC matrix [160, 162, 166-169]. These fibres have a diameter of 7-20μm [170]. Fibre-reinforced composites can be classified into two types: continuous, aligned fibres with anisotropic properties and discontinuous, short fibres [166, 171]. The fibre type used for composite reinforcement depends on the intern properties correlated with requirements of the clinical case.

These materials combine the mechanical properties of the fibre with those of the matrix. The fibres exhibit increased tensile strength and elasticity, and low shear strength; the polymeric matrix is characterized by increased hardness [172]. When compared with other structural materials, FRC materials present high stiffness and strength per weight along with adequate toughness [158]. Reinforcing technology is used when low-weight structures that can take up high stresses are needed, as it is the case with dental restorations.

Nowadays, fibre reinforced composites (FRCs) are increasingly applied in dentistry, in a variety of disciplines: restorative dentistry, periodontology, prosthodontics, orthodontics

In dental applications, these materials are usually subjected to flexure or bending. While clinical performance is the final criterion of success, flexure is still the most widely reported mechanical property, and test results are useful in developing and selecting new materials for clinical use [163, 164].

FRCs are used for stabilization of mobile teeth with compromised periodontal support, also allowing the rehabilitation of masticatory function. In the scientific literature very few studies are mentioned regarding the combination of different types of fibres with different types of composite resins [164, 173, 174].

After 30 years of sustained development of physical, chemical and biomechanical properties, FRCs have currently a variety of applications in dentistry: fixed and removable prosthodontics (including repairing of fractured porcelain veneers, repairing and reinforcing of removable acrylic resin prosthesis), periodontology (periodontal splints), orthodontics (retainers and space maintainers), and restorative dentistry (root canal posts) [166, 173, 175-180]. However, current designs of FRC bridges do not provide an adequate lifespan, the survival rate being reported as 73.4% at 4.5 years [176]. The most plausible reason is the insufficient information regarding the effect of design parameters on mechanical performance of FRC bridges [181] this factor explaining also the practitioners' and technicians' reluctance in using this prosthesis.

My research on FRCs focused on their use in the field of periodontology and prosthodontics, as splints and fixed dental prothesis, respectively. I started using FRC 20 years ago and witness their evolution and improving performances. The numerous cases I encountered as a practitioner, offered me the possibility of observing and better understanding their limits and possibilities and define some directions of research. The internal grant I was a director on, helped me in deepening the research on the topic and obtaining original results with practical outcome.

In addition to biomechanical studies, I developed a series of finite element analyses, extended to different types of indirect restorations, in order to visualize and better understand the dynamic of constraints in some particular cases. The intention was to create 4 models –

clinical, physical, mathematical and computational and each of the four meant to bring new insights in understanding the biomechanical phenomenon and also to support the validity of the other three models. This vision is still a work in progress, but important steps have already been done.

2.2.1. BIOMECHANICS OF FRC AS PERIODONTAL SPLINTS

2.2.1.1. State of the art

Research supports the use of periodontal splinting as a recommended therapy to stabilize mobile teeth in order to improve long-term prognosis [182-184].

In the context of periodontal disease, occlusal forces can exacerbate a pre-existing periodontal lesion when they exceed the resistance threshold of a compromised epithelial attachment [185-187]. Periodontal disease and occlusal trauma occur predominantly in the anterior region of the mandible. Although occlusal forces may be lower in this region than other areas of the mandible, deformations may be larger as the bone size is smaller [188, 189]. In the effort of properly distributing the occlusal load, different types of periodontal splints are employed.

An important aspect in choosing the periodontal splint type is the mechanical interaction between the materials used and the dento-periodontal substrate [190, 191]. There is limited literature on the impact of bone resorption and periodontal immobilization on the biomechanical response of bone-tooth-periodontium complex.

Therefore, the use of immobilization and the choice of its type remains a difficult decision for practitioners. Several methods can be used to clarify these aspects, each of which presents advantages, disadvantages, and limitations: the photoelasticity method, the resistive electric tensometry method, mechanical compressive and tensile strength tests, and the finite element method [192, 193]. Regardless of the method, when a mandibular model is intended to simulate different clinical situations, choosing the right material for replicating the alveolar bone is a decisive aspect. This material must be isotropic, even though the bone is not a homogeneous structure, and must exhibit mechanical and elastic properties similar to the mandibular bone.

Periodontitis is a chronic infectious disease of the tissues surrounding the teeth, caused by specific microorganisms or groups of specific microorganisms, characterized by gingival inflammation, loss of connective tissue attachment and destruction of alveolar bone [194-196]. With the reduction of periodontal attachment, mobility and dental migration appear, resulting in incorrectly distributed occlusal forces, which overload the already affected periodontal system. The relationship between occlusal trauma and tooth mobility depends on the intensity and frequency of occlusal forces [185].

The treatment of dental mobility in periodontal disease is determined by the degree of bone resorption. For teeth with increased mobility due to widening of periodontal space induced by the adaptation to the functional conditions of mastication, the treatment is a combination of occlusal adjustments and periodontal therapy.

For teeth affected by gingival inflammation and increased mobility due to bone resorption, the treatment is a combination of periodontal therapy, occlusal adjustments and teeth immobilization [185, 197-199]. Stabilization is achieved by periodontal splinting, which leads to redistribution of functional and para-functional occlusal forces. This helps the reorganization of the gum tissues, the periodontal fibres and the alveolar bone, consequently improving the masticatory and patient comfort [186, 187]. The use of periodontal splint before the surgical treatment improves the predictability of the procedures and the tissues healing if the tooth movement is eliminated [200]. But still, it is a controversial issue.

There are numerous immobilization systems: composite resins [185, 188, 201], wire mesh [201, 202], fibre-reinforced composites [185, 201, 203].

The research in this direction implied 3 stages: the first stage focused on testing the mechanical and elastic properties of fibre-reinforced composite systems with different fibers in association with different types of composites. As a result, we chose the systems that presented the best performance for further testing. The second stage aimed at evaluating the biomechanical behavior of the bone-tooth-periodontium complex and of the FRCs selected systems, in various clinical scenarios, by in vitro methods and by numerical methods, considering the mechanical interaction between the materials, the design of the periodontal splint and the dento-periodontal substrate. The last stage was a longitudinal clinical study on the evolution of periodontal status and on clinical behavior of periodontal splints. Based on the results obtained from previous studies, the criteria for selecting patients and splint systems were defined.

	Most relevant personal scientific contributions in this field (the highlighted papers are presented in extenso in the next chapters):
ISI	1. Vieriu RM, Ţănculescu O*, Mocanu F, Doloca A, Martu S. *A comparative study of mechanical properties of different types of fibre reinforced composites used in periodontal therapy*. Materiale Plastice 2015;52(2):266-271. FI = 0,824/2014 http://www.revmaterialeplastice.ro/pdf/VIERIU%20R.pdf%202%2015.pdf 2. Vieriu RM, Ţănculescu O*, Mocanu F, Solomon SM, Sandu IG, Savin C, Bosînceanu DG, Săveanu IC, Sălceanu M, Apostu AM, Doloca A, *In vitro study regarding the biomechanical behaviour of bone and periodontal splints. I. Model validation*, Materiale Plastice, 2019; 56(4):1013-1020. IF = 1,393 https://www.revmaterialeplastice.ro/Articles.asp?ID=5300 3. Vieriu RM, Ţănculescu O*, Mocanu F, Solomon SM, Savin C, Bosînceanu DG, Doloca A, Iordache C, Ifteni G, Săveanu I. *In vitro study regarding the biomechanical behaviour of bone, fibre reinforced polymer and wire composite periodontal splints. II. Model analysis*. Materiale Plastice. 2020, 57(1):253-262, DOI:10.37358/MP.20.1.5334. IF = 1,393 https://revmaterialeplastice.ro/pdf/29%20VIERIU%201%2020.pdf
IDB	1. Vieriu RM, Mocanu F, Ţănculescu O*, Doloca A, Mârțu S. *Flexural and shear strength of fibre reinforced composites used in periodontology*. Bul. Inst. Polit. Iasi, 2015, t. LXI (LXV), f. 1, 47-57 https://cmmi.tuiasi.ro/wp-content/uploads/buletin/2015%20fasc%201/L4%20CM%201_2015.pdf 2. Vieriu RM, Ţănculescu O*, Mocanu F, Aniculăesă A, Doloca A, Luchian I, Mârțu S. *The validation of an acrylic resin for the completion of biomechanical studies on a mandibular model.* Romanian Journal of Oral Rehabilitation. 2015, 7(2):74-79, ISSN 2066-7000 http://www.rjor.ro/the-validation-of-an-acrylic-resin-for-the-completion-of-biomechanical-studies-on-a-mandibular-model/?lang=ro 3. Vieriu RM, Ţănculescu O*, Savin C, Solomon S, Sălceanu M, Săveanu IC. *Parameters that influence the properties of fibre-reinforced composites. Review*. Romanian Journal of Oral Rehabilitation, 2019, 11(3):198-204 http://www.rjor.ro/parameters-that-influence-the-properties-of-fibre-reinforced-composites-review/ 4. Vieriu RM, Ţănculescu O*, Săveanu IC, Ciur MD, Balcoș C, Doloca A, Apostu A, Mârțu S. *Clinical study on fibre reinforced composite and wire-composite periodontal*

splinting and their influence on periodontal progress status. Romanian Journal of Oral Rehabilitation, 2019;11(4):145-151
http://www.rjor.ro/clinical-study-on-fibre-reinforced-composite-and-wire-composite-periodontal-splinting-and-their-influence-on-periodontal-progress-status/

2.2.1.2. Physical properties of FRC used in periodontology

Aim of the study

The aim of this study was to assess and compare the shear strength of the fibre and flexural strength of composites for different types of fibre reinforced composite. The considered tested specimens were symmetric sandwich beams with two identical layers (composite) and a continuous core (fibre).

Materials and method

a. *Specimen preparation*

A total of 80 bar-shaped specimens with the following dimensions 2x2x25 mm were fabricated according to ISO Standard 4049/2000 [204]. The specimens were divided in 16 groups (n=5), according to the fibre type and width (*Construct* - polyethylene fibre 2 and 3 mm, *Interlig* - braided glass fibre 2 mm, *Splint-It* - unidirectional glass fibre 3 mm) and composite resin (*Filtek Z250*, *Premise Packable*, *Premise Flowable*, *Brilliant Flowable*) used:

- CF2 (Construct 2 mm +Filtek Z250) - A1
- IF2 (Interlig 2 mm +Filtek Z250) - A2
- CF3 (Construct 3 mm + Filtek Z250) - A3
- SF3 (Splint-It 3 mm +Filtek Z250) - A4
- CPP2 (Construct 2 mm + Premise Packable) - B1
- IPP2 (Interlig 2 mm + Premise Packable) - B2
- CPP3 (Construct 3 mm + Premise Packable) - B3
- SPP3 (Splint-It 3 mm +Premise Packable) - B4
- CPF2 (Construct 2 mm + Premise Flowable) - C1
- IPF2 (Interlig 2 mm + Premise Flowable) - C2
- CPF3 (Construct 3 mm + Premise Flowable) - C3
- SPF3 (Splint-It 3 mm + Premise Flowable) - C4
- CBF2 (Construct 2 mm + Brilliant Flowable) - D1
- IBF2 (Interlig 2 mm + Brilliant Flowable) - D2
- CBF3 (Construct 3 mm + Brilliant Flowable) - D3
- SBF3 (Splint-It 3 mm + Brilliant Flowable) - D4

The tested specimens have a sandwich structure which consists of two-layer composite resin, having the same thickness (approximate 0.9 mm) and fibre (0.2 mm), a continuous core, made of a solid material, which joints the two layers (Fig. 10). This structure provides a very high level of bending stiffness. The primary function of the core is to transfer shear force between the faces without failure or excessive deformation.

It is considered that the core material and the two layers are isotropic and the three components have a perfect adhesion between them and work as a coherent unit.

The specimens were stored at room temperature in distilled water for 24 hours before mechanical testing. The specimens made of different FRC systems were subjected to a three-point bending test (Fig. 11). This test may be used to determine the shear strength and flexural strength of the face sheets. Both bending and interlaminar shear stresses are induced in the beam.

For three-point loading, the maximum bending moment in the beam is at midspan and is equal to $M_{\max} = Fl/4$, where F is the central load applied and l is the span length. The transverse shear force, hence the interlaminar shear stress in the beam, is equal to $T = F/2$ and is constant over the entire support span (Fig. 11).

The specimens were tested with static short duration loads on a universal testing machine type WDW-5CE which can be operated in force or strain control as well as (crosshead) displacement control. An electronic load cell and multiple channel strain-displacement signal conditioning electronics feed into a computerized controller, which processes these data and presents and stores the results in the desired form (stress-strain, stress-displacement, and strain-strain plots). The load was applied at the middle of the test specimens, perpendicular to the long axis, with a rounded-ended striker (Fig. 12). The static testing has been performed at room temperature and normal humidity conditions. Testing was conducted at a crosshead displacement rate of 0.5 mm/min.

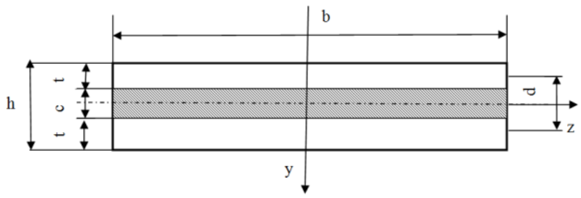


Fig. 10. Structural sandwich consisting of two face sheets and a continuous core [9]

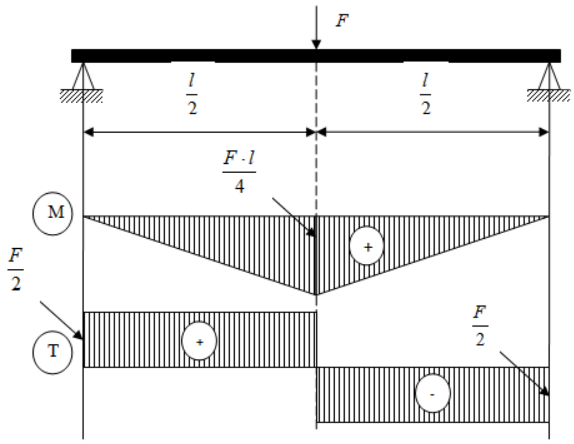


Fig. 11. Three-point bending loading configuration [10]

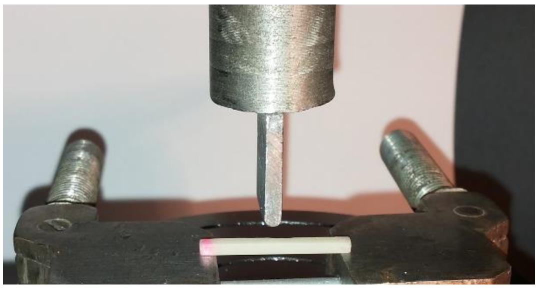


Fig. 12. FRC specimen in three point bending test

b. Flexural strength

The axial bending stresses are compressive on the surface of the beam where the load is applied and tensile on the opposite surface, varying linearly through the beam thickness (Navier relation) [172]. The flexural strength in the face sheets varying linearly through the composite thickness is calculated with formulae [205]:

$$\sigma_c = \frac{M \cdot E_c}{D} \cdot y, \ for \begin{cases} -h/2 \le y \le -c/2 \\ c/2 \le y \le h/2 \end{cases} \qquad 1)$$

The maximum bending stress, in the face sheets, at midspan is given by:

$$\sigma_{c\max} = \frac{M_{\max} \cdot E_c}{D} \cdot \frac{h}{2} = \frac{F_r \cdot l}{D} \cdot \frac{E_c h}{8} \qquad 2)$$

where: h – the beam height, D - the bending stiffness per unit width calculated with the formulae (3), F_r - the fracture force.

The bending stiffness per unit width is the product of face elastic modulus and moment of inertia [172]. So:

$$D = 2 \cdot E_c \cdot I_c = 2 \cdot E_c \left[\frac{bt^3}{12} + bt \cdot \left(\frac{d}{2} \right)^2 \right] = \frac{bt}{2} E_c \cdot \left[\frac{t^2}{3} + (c+t)^2 \right] \qquad 3)$$

where: t – the face sheets thickness, c – the core thickness, b – the beam width,

d – the distance between the centers of gravity of the face sheets: $d = c + t$ (Fig. 10), E_c - face elastic modulus, I_c - moment of inertia of face sheets (calculated of Steiner formulae) [205].

c. Shear strength

The shear strength on the height of a sandwich structure is calculated with Juravschi relation:

$$\tau = \frac{T}{D \cdot b} \cdot (S \cdot E_f) \qquad 4)$$

where: T - the transverse shear force ($T = F/2$), E_f - elastic modulus of the core (fibre), $S \cdot E_f$ - the product of moment static and core elastic modulus.

In the core, for $-c/2 \leq y \leq c/2$ it can be written:

$$S \cdot E_f = \frac{b}{2} \cdot \left(\frac{c}{2} - y \right) \cdot \left(\frac{c}{2} + y \right) \cdot E_f \qquad 5)$$

D - the stiffness per unit width is:

$$D = E_f \cdot I_f = E_f \cdot \frac{bc^3}{12} \qquad 6)$$

Substitution of (5) and (6) into equation (4) gives:

$$\tau = \frac{F}{2} \cdot \frac{1}{E_f \cdot \frac{bc^3}{12}} \left[\frac{1}{2} \cdot \left(\frac{c^2}{4} - y^2 \right) \cdot E_f \right] = \frac{3F}{bc^3} \cdot \left(\frac{c^2}{4} - y^2 \right) \qquad 7)$$

In the neutral plane where the bending stress passes through zero the interlaminar shear stress is maximum, varying parabolically from zero on each surface of the beam [205]. For a beam of rectangular cross section, the shear stress is maximum on the beam axis (for y=0) and is given by [206]:

$$\tau_{f\max} = 0,75 \frac{F_r}{bc} \qquad 8)$$

Results

The specimens were tested until fracture failure. The maximum loads, equivalent to the fracture force, were registered by the computer software and are presented in Table 16. One-way ANOVA was performed was applied to maximum loads, having first verified that the data met the requirements of normal distribution and homogeneity of group variances. In all the analyses, the level of significance was set at $\alpha = 0.05$ and calculations were done by the SPSS 18.0 software (SPSS; Chicago, IL, USA).

The bending stiffness was calculated using formula (3).

Table 16. Maximum load and bending stiffness of specimens

Groups (n=5)	*Maximum load (N)*		*Bending stiffness ($N \cdot mm^2$)*
	Average	*Std. Dev.*	
CF2-A1	14.80	0.66	**15051.6**
IF2-A2	17.03	1.31	
CF3-A3	52.20	1.41	**22577.4**
SF3-A4	21.04	1.48	
CPP2-B1	14.42	0.99	**13586.4**
IPP2-B2	17.01	0.85	
CPP3-B3	39.20	1.63	**20379.6**
CPP3-B4	23.04	1.03	
CPF2-C1	22.40	1.26	**10323**
IPF2-C2	28.60	0.93	
CPF3-C3	40.03	1.27	**15484.5**
SPF3-C4	36.60	1.72	
CBF2-D1	13.61	0.73	**6926.4**
IBF2-D2	18.76	0.96	
CBF3-D3	30.78	1.23	**10389.6**
SBF3-D4	30.62	1.43	

Table 17. One-way ANOVA results for maximum load

	Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*
Maximum load (N)	Between Groups	9464.86	15	630.99	424.17	**<0.001**
	Within Groups	95.21	64	1.49		
	Total	**9560.06**	**79**			

Table 18. Flexural and shear strength of specimens

Groups (n=5)	**Flexural strength (MPa)**				**Shear strength (GPa)**			
	Sum	**Average**	**Std. Dev.**	**Variance**	**Sum**	**Average**	**Std. Dev.**	**Variance**
CF2-A1	277.8	55.56	2.48	6.15	138.75	27.75	1.24	1.53
IF2-A2	320.2	64.04	4.93	24.29	159.6	31.92	2.46	6.03
CF3-A3	653.15	130.63	3.53	12.47	326.25	65.25	1.76	3.11
SF3-A4	263.26	52.65	3.72	13.81	131.5	26.3	1.86	3.45
CPP2-B1	271.09	54.218	3.73	13.91	135.15	27.03	1.86	3.46
IPP2-B2	319.25	63.85	3.18	10.13	159.45	31.89	1.59	2.53
CPP3-B3	490.51	98.10	4.09	16.73	245.01	49.002	2.04	4.17
CPP3-B4	288.8	57.76	2.58	6.68	143.96	28.792	1.29	1.66
CPF2-C1	421.14	84.23	4.73	22.41	209.94	41.988	2.36	5.57
IPF2-C2	536.8	107.36	3.51	12.29	268.09	53.618	1.75	3.06
CPF3-C3	501.83	100.37	3.19	10.20	250.14	50.028	1.59	2.53
SPF3-C4	458.8	91.76	4.30	18.51	228.7	45.74	2.14	4.60
CBF2-D1	255.92	51.18	2.75	7.57	127.55	25.51	1.37	1.88
IBF2-D2	351.74	70.348	3.58	12.78	175.84	35.168	1.79	3.19
CBF3-D3	385.11	77.02	3.07	9.42	192.34	38.468	1.53	2.35
SBF3-D4	382.73	76.55	3.59	12.87	191.33	38.266	1.79	3.22

It was observed that the first fracture line appeared along the axis of the force, on the compressive surface of the specimen. The crack progressed toward the junction area between the fibre and the composite veneer and subsequently the crack propagated along the fibre. In the final stage, catastrophic failure appeared at the tension side. It is important to correlate the flexural strength of the composite sheets to the flexural strength of the entire FRC specimen. In order to calculate the flexural strength of the composite, we used formulae (2), where the values of the maximum load supported by each specimen and of the bending stiffness are given in Table 16.

Table 19. One-way ANOVA results for flexural and shear strength

	Source of Variation	SS	df	MS	F	P-value	F crit
Flexural strength (MPa)	Between Groups	40203.4	15	2680.23	203.98	5.4E-48	1.83
	Within Groups	840.96	64	13.14			
	Total	41044.35	79				
Shear strength (GPa)	Between Groups	10030.09	15	668.67	204.34	5.11E-48	1.83
	Within Groups	209.43	64	3.272			
	Total	10239.52	79				

An important aspect is the interfacial adhesion between composite sheets and the fibre reinforcement. Interlaminar shear stress occurs in this area and influences the integrity of the FRC specimen, by delamination. The maximum shear strength at the composite - fibre interface was calculated with formulae (8). The values of flexural and shear strength are presented in Table 18.

Discussions

For all FRC, it was observed that the shear strength was approximately 50% lower than the flexural strength of the composite. This aspect implies that the destruction of the specimens was due to composite fracture, and that the interlaminar shear stress represents a secondary mechanism of failure.

The fibre width influences the resistance of the specimens. Considering the different widths of polyethylene fibres, one can notice that the flexural strength and the shear strength were higher in specimens with 3 mm than in groups with 2 mm fibre, for all types of composite used:

- $\sigma_{CF3} > \sigma_{CF2}$ with 135%
- $\sigma_{CPP3} > \sigma_{CPP2}$ with 81%
- $\sigma_{CPF3} > \sigma_{CPF2}$ with 19%
- $\sigma_{CBF3} > \sigma_{CBF2}$ with 50%.

Regarding the influences of the fibre type on the flexural strength, there were noticed the following:

- in the groups with 3 mm fibres and Filtek Z250, the flexural strength of the composite was 2.5 higher for Construct than for Splint-It.
- in the groups with 3 mm fibres and Premise Packable, the flexural strength of the composite was 1.7 higher for Construct than for Splint-It.
- in the groups with 2 mm fibres and Brilliant flow, the flexural strength of the composite was with 37% higher for Interlig than for Construct.

Comparing only the groups with glass fibres, it should be pointed out that for IF2, IPP2 and IPF2 groups (Interlig samples) the values of flexural strength and of shear strength were higher compared with SF3, SPP3 and SPF3 groups (Splint-It samples) (12-23%), even if the width of Splint-It (3 mm) is higher than the width of Interlig (2 mm).

It is reported that an increase in fibre volume results in improvement of mechanical properties [167, 207, 208]. However, an increase in load bearing capacity is not exclusively caused by higher fibre volume, but also by the strength of the resin matrix, the bonding between fibres and matrix and deterioration by water sorption of fibres and matrix [168, 209-212].

From the clinical point of view, the fact that the fracture of the composite appears first and then the crack progresses along the fibre, offers a window of opportunity to the clinician allowing him to repair the restoration intra-orally before the fibre gets impregnated with saliva.

Conclusions

Both the type of the fibre and the type of the composite have a great influence on the shear and flexural strength of FRC specimens.

For all specimens, the flexural strength was significantly higher than the shear strength (50%), which implies that the destruction of the specimen is primarily due to composite fracture and secondarily to the delamination at the interface between the composite and the fibre.

The fibre width influences the resistance of the specimens. For the specimens with different widths, it was noticed that the flexural strength and the shear strength were higher in specimens with 3 mm than in groups with 2 mm fibre, for all types of composites used; the most important difference was registered between groups CF2-CF3 (135%).

The specimens which exerted the best ratio between high flexural strength and high shear strength have the best indications to be used in periodontal therapy for dental splinting.

The potential of these restorations that replace metal, with all disadvantages that they carry, allow minimal preparation with exceptional aesthetic results at very affordable costs in a short time. This is very motivating and appealing to many specialists and patients. Nevertheless, the high variability of materials and techniques combined with the execution sensitivity and overall the reported survival rate can be discouraging for some practitioners.

Based on the critical evaluation of the available FRC systems, recommendations for individualized clinical FRC selection can be made, which is of great importance for successful outcomes of periodontal splints.

2.2.1.3. Mechanical properties of different types of FRC used in periodontal therapy

Aim of the study

This study was designed to investigate the influence of fibre type and design, resin impregnation and type of composite on mechanical properties of fibre reinforced composite. The aim was to assess and compare (1) the maximum load, (2) the maximum deflection, (3) the flexural strength, (4) the flexural modulus and (5) the fracture pattern for different systems of fibre reinforced composite.

Materials and method

To evaluate and compare different systems of fibre reinforced composites, the objective was to vary different parameters which can influence the characteristics of the samples: (1) different types of fibres glass and polyethylene, (2) different designs-unidirectional and braided, (3) different treatments of the fibre - with or without impregnation, (4) different widths of the fibre - 2 and 3 mm, (5) different types of composites - packable and flowable, microhybrid and nanohybrid. Details of the materials used in this experimental study are given in Table 20.

a. *Specimen preparation*

A total of 80 specimens were divided in 16 groups (n=5) (Table 21) and prepared according to ISO Standard 4049/2000 [213].

The first step was to fabricate a stainless-steel bar-shape specimen with the following measurements: 2x2x25 mm. After recording the impression of the bar with polysiloxane condensation silicon (Zetaplus, Zhermack, Badia Polesine, Italy, and batch number 192139) we obtain a mold with the established dimensions (Fig. 13, Fig. 14). A first increment of 0.9 thickness of resin composite was layered in each mold and then a 25 mm long segment of fibre was placed on top of the composite. In the groups where Construct fibre was used, the fibre was previously hand impregnated with the manufacturer specified resin (Construct Resin, Kerr) (Fig. 15, Fig. 16).

Table 20. Materials used for specimen preparation

Product	*Manufacturer*	*Batch no.*	*Material and chemical composition*
Construct	Kerr	5102784, 5116767	Ultra-high strength, cold gas plasma-treated silanated biaxial braided polyethylene fibres
Construct Resin	Kerr	5100456	Fumed silica, grounded barium alumina-borosilicate, dimethacrylate resins, silane
Interlig	Angelus	30643	Braided glass fibre impregnated with light cured composite resin
Splint-it	Pentron	182141	Unidirectional glass fibre impregnated with resin
Filtek Z250	3M Espe	N602076	Microhybrid composite
Premise Packable	Kerr	4957927	Trimodal nano-filled composite
Premise Flowable	Kerr	5123370	Trimodal nano-filled composite
Brilliant Flowable	Coltene	F52923	Nano-filled composite

Table 21. The specimens divided in 16 groups varying the type and the width of the fibre and the composite resin used

Specimens divided in groups (n=5)	*Type of fibre*	*Width of fibre*	*Composite resin*
A1	Construct	2 mm	Filtek Z250
A2	Interlig	2 mm	Filtek Z250
A3	Construct	3 mm	Filtek Z250
A4	Splint-it	3 mm	Filtek Z250
B1	Construct	2 mm	Premise Packable
B2	Interlig	2 mm	Premise Packable
B3	Construct	3 mm	Premise Packable
B4	Splint-it	3 mm	Premise Packable
C1	Construct	2 mm	Premise Flowable
C2	Interlig	2 mm	Premise Flowable
C3	Construct	3 mm	Premise Flowable
C4	Splint-it	3 mm	Premise Flowable
D1	Construct	2 mm	Brilliant Flowable
D2	Interlig	2 mm	Brilliant Flowable
D3	Construct	3 mm	Brilliant Flowable
D4	Splint-it	3 mm	Brilliant Flowable

The light-curing of the specimens was performed three phases, 20 seconds of light-exposure for each of the three thirds. The LED curing light unit had 1100 mW/cm^2 power and, 430-480 nm wavelength and it was positioned at 5 mm distance between the tip and the specimen (Fig. 16).

A second layer of composite resin was applied to fill up the mold and it underwent the same curing procedure (Fig. 17). After taking the specimens out of the mold, the thickness and the width were measured using a digital micrometer with an accuracy of 0.01 mm. The specimens were finished with a silicon carbide grinding paper, until the dimensions of 2±0.05 mm in height and in width were obtained. All the procedures were performed by the same person in order to calibrate the protocol. The specimens were stored at room temperature in distilled water for 24 hours before mechanical testing.

Fig. 13. The impression of the stainless-steel bar

Fig. 14. The silicone mold

Fig. 15. First layer of composite with 0.9 mm thickness

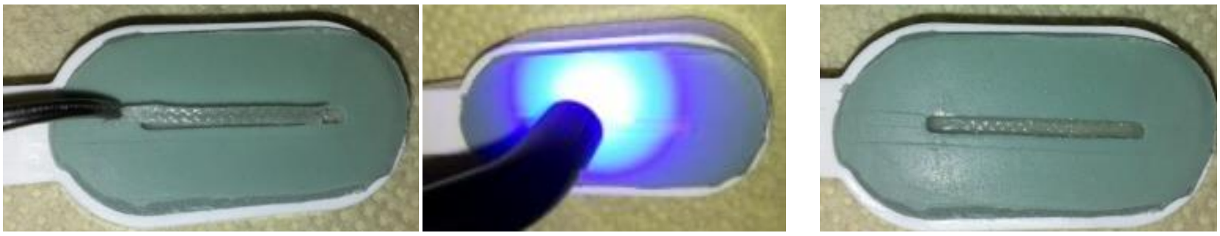


Fig. 16. Placing of the fibre on the first layer of composite and light curing for 60 seconds

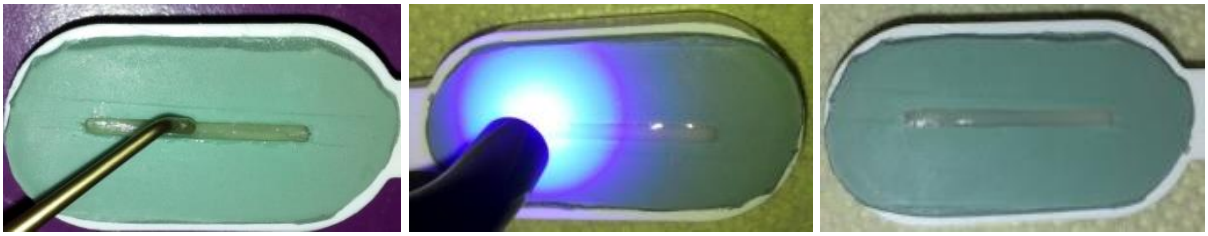


Fig. 17. Placing the second layer of composite and light curing for 60 seconds

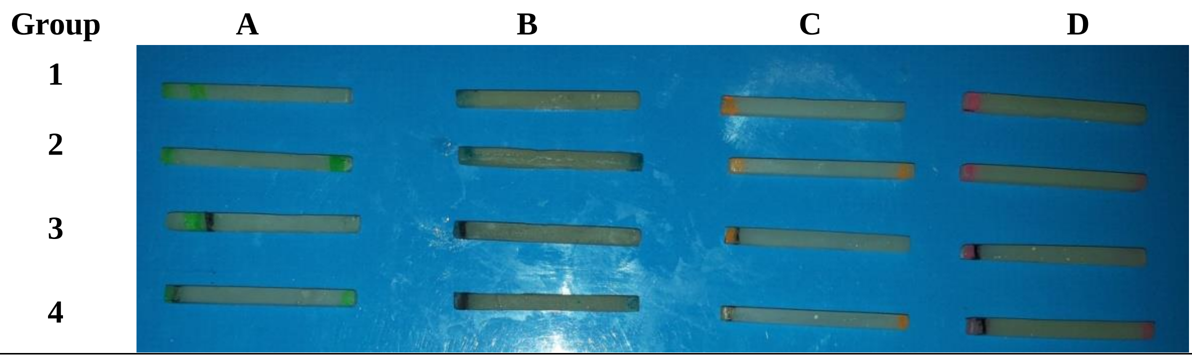


Fig. 18. Specimens' categorization in one of the 16 groups with colorimetric marks

b. Mechanical testing

A three-point bending test was carried out to assess the flexural strength and the flexural modulus of the specimens. The specimens have been tested with static short duration loads on a universal testing machine type WDW-5CE and with a distance of 20 mm between the two supports. The load was applied at the middle of the test specimens perpendicular to the long axis, with a rounded-ended striker at a crosshead speed of 0.05 mm/min, in order to avoid the impact shock. The static testing has been performed at room temperature and normal humidity conditions. During testing, the load-deflection curves were recorded with computer software.

Ultimate flexural strength (σ) was calculated with Navier formulae [205]:

$$\sigma_{\max} = \sigma_r = \frac{M_{\max}}{W_z} = \frac{\frac{F_r \cdot l}{4}}{\frac{b \cdot h^2}{6}} = \frac{3}{2} \cdot \frac{F_r \cdot l}{b \cdot h^2} \quad (1)$$

Where:

$M_{\max}$ - maximum flexural momentum;

Wz - strength modulus of the transversal section;

F_r - the applied load at the highest point of load-deflection curve (N);

l - the span length, the distance between the supports (20 mm);

b - the width of the test specimen (2 mm);

h - the thickness/ height of the test specimen (2 mm).

The flexural modulus *(E)* was calculated with the following formulae:

$$E = \frac{F_r \cdot l^3}{4 \cdot f_{\max} \cdot bh^3} \quad (2)$$

Where:

- F_r*, l, b, h* have the same interpretation as in the previous formulae

- $f_{\max}$ - the deflection corresponding to load F at a point in the straight-line portion of the trace.

c. SEM observations

The structure of each tested specimen was examined using a scanning electron microscope (SEM QUANTA 200 3D, FEI Netherlands). The surface was scanned and observed on the screen at 200x, 300x, 1000x, 5000x, 10000x magnifications.

d. Statistical methods

The collected data was subjected to a one-way analysis of variance (ANOVA). All tests were performed at a significance level of $\alpha = 0.05$. Statistical software STATISTICA (data analysis software system, version 8.0., StatSoft, Inc.) was used for statistical data analysis.

Results

The specimens were tested until fracture failure or until they were displaced from the support. It was noticed that the first fracture line appeared along the axis of the force, on the compression side - the inferior part of the composite. The crack evolved until the junction layer between the fibre and the composite veneer and then the fracture was spreading along the fibre. In the last stage, cracks appeared at the compression side - the superior part of the composite.

The fracture failure describes two patterns: the complete transversal separation of the specimens in two parts and the delamination of the composite, while maintaining the fibre integrity (Fig. 19).

The maximum loads, equivalent to the fracture force and the maximum deflection of the specimens, are presented in Table 22 and Table 23. The flexural strength and flexural modulus values were calculated (Table 25) based on the Table 24 values and the formulas (1) and (2).

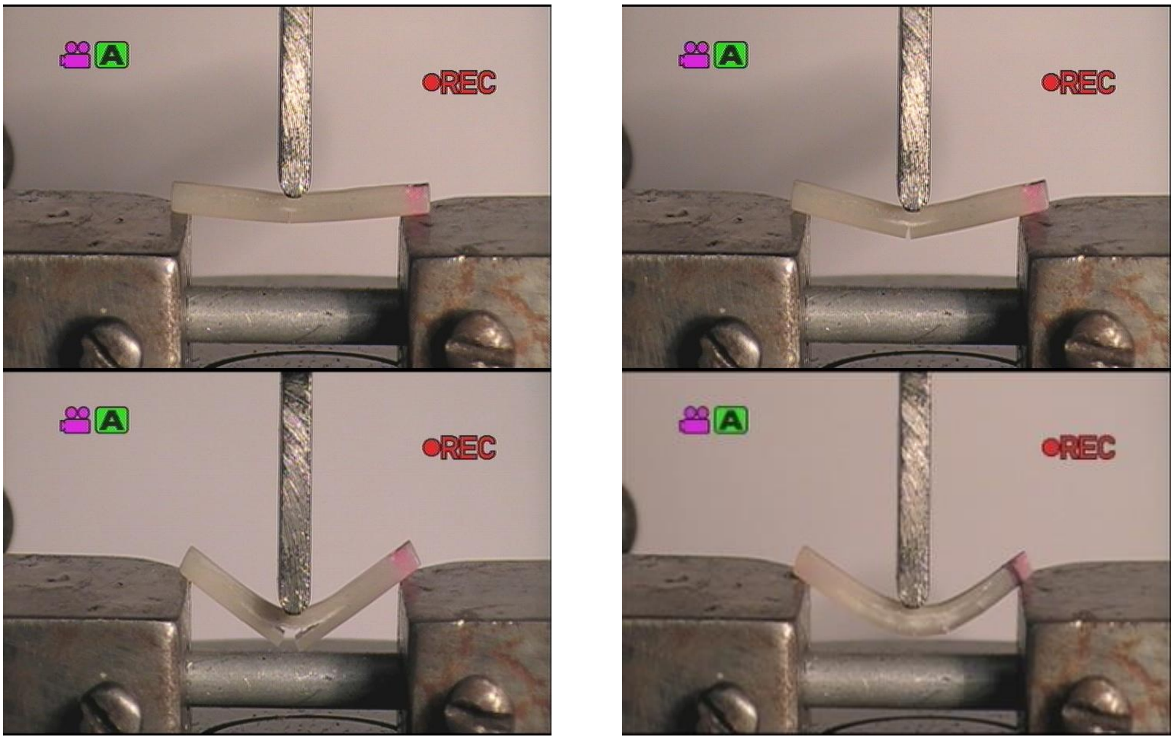


Fig. 19. Stages of the three-point bending test

Table 22. Maximum load and maximum deflection values

Groups (n=5)	Maximum load (N)				Maximum deflection (mm)			
	Sum	**Average**	**Std. Dev.**	**Variance**	**Sum**	**Average**	**Std. Dev.**	**Variance**
A1	74,01	14,80	0,66	0,44	28,29	5,66	0,85	0,73
A2	85,14	17,03	1,31	1,71	11,69	2,34	0,60	0,36
A3	261,00	52,20	1,41	1,99	28,20	5,64	0,68	0,47
A4	105,21	21,04	1,48	2,20	7,45	1,49	0,61	0,38
B1	72,08	14,42	0,99	0,98	15,46	3,09	0,67	0,44
B2	85,06	17,01	0,85	0,72	14,79	2,96	0,50	0,25
B3	196,02	39,20	1,63	2,67	35,81	7,16	0,70	0,49
B4	115,19	23,04	1,03	1,06	9,26	1,85	0,39	0,15
C1	111,98	22,40	1,26	1,58	36,55	7,31	0,69	0,48
C2	143,01	28,60	0,93	0,87	11,83	2,37	0,52	0,27
C3	200,14	40,03	1,27	1,62	28,92	5,78	0,52	0,27
C4	182,99	36,60	1,72	2,95	13,55	2,71	0,61	0,37
D1	68,04	13,61	0,73	0,53	35,45	7,09	0,67	0,46
D2	93,80	18,76	0,96	0,91	19,59	3,92	0,54	0,29
D3	153,90	30,78	1,23	1,51	31,25	6,25	0,63	0,39
D4	153,10	30,62	1,43	2,06	20,09	4,02	0,52	0,27

Table 23. One-way ANOVA results for maximum load and maximum deflection

	Source of Variation	SS	df	MS	F	P-value
Maximum load (N)	*Between Groups*	9464,86	15	630,99	424,17	<0,001
	Within Groups	95,21	64	1,49		
	Total	9560,06	79			
Maximum deflection (mm)	*Between Groups*	310,64	15	20,71	54,80	<0,001
	Within Groups	24,19	64	0,38		
	Total	334,83	79			

Table 24. Flexural strength and flexural modulus values

Groups (n=5)	Flexural strength (MPa)				Flexural modulus (GPa)			
	Sum	Average	Std. Dev.	Variance	Sum	Average	Std. Dev.	Variance
A1	913,85	182,77	7,22	52,12	10,01	2,00	0,31	0,10
A2	1051,66	210,33	16,82	282,98	28,93	5,79	1,59	2,53
A3	3222,98	644,60	14,28	203,90	35,14	7,03	0,79	0,63
A4	1299,22	259,84	18,01	324,28	59,67	11,93	4,41	19,49
B1	890,22	178,04	12,46	155,22	18,02	3,60	0,64	0,41
B2	1050,51	210,10	10,68	113,99	22,26	4,45	0,99	0,99
B3	2420,48	484,10	18,16	329,70	20,69	4,14	0,38	0,14
B4	1422,50	284,50	12,34	152,38	48,74	9,75	2,42	5,84
C1	1383,20	276,64	16,73	279,76	11,62	2,32	0,30	0,09
C2	1766,07	353,21	11,01	121,20	46,95	9,39	1,76	3,09
C3	2471,53	494,31	14,53	211,18	26,13	5,23	0,41	0,17
C4	2259,54	451,91	19,28	371,83	52,68	10,54	2,27	5,13
D1	840,27	168,05	9,04	81,68	7,28	1,46	0,20	0,04
D2	1158,26	231,65	11,08	122,83	18,18	3,64	0,35	0,12
D3	1900,64	380,13	15,31	234,39	18,60	3,72	0,27	0,07
D4	1891,01	378,20	19,07	363,67	29,15	5,83	1,03	1,06

Table 25. One-way ANOVA results for flexural strength and flexural modulus

	Source of Variation	SS	df	MS	F	P-value
Flexural strength (MPa)	*Between Groups*	1443128	15	96208,51	452,60	<0,001
	Within Groups	13604,45	64	212,57		
	Total	1456732	79			
Flexural modulus (GPa)	*Between Groups*	769,53	15	51,30	20,58	<0,001
	Within Groups	159,56	64	2,49		
	Total	929,10	79			

Discussions

The maximum force supported by the specimens was founded in the A3 group (52.2 ± 1.41 N) and the lowest was in the D1 group (13.61 ± 0.73 N).

Regarding the groups with 2 mm width fibre, the following observations were made: the glass fibres reinforced specimens (A2, B2, C2, D2) allow a higher load and consequently a higher fracture force, with no influence from the composite type, when compared with polyethylene fibres reinforced specimens. *Anagnostou et al.* reported higher values of the fracture force for both fibre types: 57.4±7.7 N for polyethylene reinforced specimens (Ribbond - THM) and 55.84±2.9 N for glass fibre reinforced specimens (Splint-It), but with no statistical differences between the two systems. In our study we used one type of composite for each specimen (flowable or packable), while in *Anagnostou et al.* study there were used two types of composite for the same specimen: a flowable composite on the bottom of the specimen (Flow-It, Pentron) and a medium viscosity composite above the fibre (Simile, Pentron) [214].

This study showed that different fibre types when combined with given composites have a major impact on the system flexural strengths. The results regarding the higher flexural strength of glass reinforced specimens are in concordance to those reported by *Sharafeddin* et al [163]. For the specimens reinforced with unidirectional glass fibre and Filtek Z250, *Sharafeddin* reports a flexural strength of 500±31.24 MPa, which is higher than the flexural strength found in our A2 study group (210.33±16.82 MPa). The differences can be explained by the position of the reinforcing fibre at the bottom of the specimen, which concur to an increased maximum flexural strength as *Garoushi et al.* demonstrated in previous studies [215]. In our study, the fibre was placed at the middle of the specimen [215, 216]. For Construct - Premise Flow specimens, *Juloski* reported a flexural strength of 287.62±85.91MPa, similar to that obtained in this study in C1 group - 276.64 ± 16.73 MPa [217].

The maximum deflection, which allows a partial elastic recovery, varies between 1.49±0.61mm and 7.31±0.69mm. There have been noticed high deflection values for groups A1, B1, C1 and D1, the polyethylene fibre reinforced samples. These high deflections can be correlated with a low flexural modulus. It is important to highlight that the relatively low flexural strength is sometimes desirable in order to allow a minimum of micro movements of splinted teeth, which contributes to the periodontal repair process [217].

When comparing the 2 mm polyethylene fibres with the four types of resins, one can point out that flowable resins allow a higher deflection and a low flexural modulus. Specimens reinforced with glass fibre accept a low deflection and a high flexural modulus which means a high toughness.

For specimens reinforced with 3 mm fibres, the groups with polyethylene registered higher fractures forces compared with glass fibres. The maximum flexural strength was registered in group A3 (Construct+ Filtek Z250) - 644.6 ± 14.28 MPa.

Celeste C.M. van Heumen performed meta-regression analyses and observed a lower flexural modulus of polyethylene reinforced specimens regardless the dimension, impregnation, manufacturer or type of composite. This finding is in accordance with the results achieved in the present study [173].

Al-Darwish stated that the fibreglass provided an excellent adhesion between the fibre and the resin matrix and that the reinforcing effects of fibreglass increased the mechanical qualities of the matrix [167]. Improved adhesion of composites and glass fibres could be due to the silica contents of the fibre and consequent stronger bonds which in turn lead to an increased flexural strength [163, 218]. Analyzing the fracture pattern, the strong adhesion between fibre glass and composites layers must be mentioned. In group 2 (braided glass fibre) the specimens were separated in two distinguished parts with the same structure: composite, fibre, composite (Fig. 20).

For specimens in group 4, destruction by delamination in the mass of the fibre was noticed (Fig. 21). The fracture pattern in the groups 1 and 3 (braided polyethylene fibres) is in accordance with results of Pereira et al. and Sharafeddin F. et al. studies [163, 219]. The specimens showed the fracture in two discrete parts of the inferior composite layer while it was still attached to the intact polyethylene fibre, proving the stability and firmness of the polyethylene structure (Fig.22). This means that the periodontal splint is kept in place even after the initiation of the crack which allows intraoral repair, enabling the functionality of the restoration after the initial failure. *Ellakwa* indicates that the physical and chemical properties of composite dominate the modulus of specimens and not the incorporation of fibres. This aspect is partly in agreement with the results of this study and can be applied only for group D [165]. All these aspects must be correlated with information about clinical survival of periodontal splints, in order to obtain the best clinical outcome of fibre reinforced composites restorations [184].

Fig. 20. The fracture pattern of FRC with braided glass (groups B2, D2)

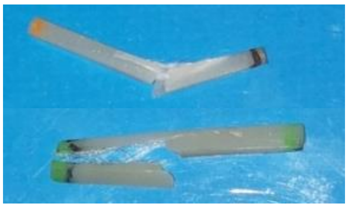


Fig. 21. The fracture pattern of FRC with unidirectional glass (groups B4, C4)

Fig. 22. The fracture pattern of FRC with polyethylene (groups A1, C1, D1)

Conclusions

Within the limitations of the experimental design, the following were concluded:

1. The type of the fibre has a great influence on the flexural strength of specimens.
2. The specimens which exerted the best ratio between high deflection, low flexural modulus and medium flexural strength have the best indications to be used in periodontal therapy.
3. Regarding fracture pattern, the specimens which have been separated in two discrete parts while maintaining the polyethylene fibre intact are indicated for splinting because they allow intraoral repairs, increasing the longevity of the restorations.

2.2.1.4. Biomechanical behavior of bone and periodontal splints

This study aims to evaluate the biomechanical behaviour of anterior mandibular bone and periodontal splinting systems subjected to different occlusal forces by means of electric resistive tensometry (ERT). ERT represents a non-destructive method for measuring the deformations (strains) of a mechanically loaded object with a resistive electrotensometric transducer (strain gauge - SG) which transforms the mechanical deformation variations in electrical resistance variations [220, 221]. Previous research have measured bone strain using strain gauges at the level of dental supporting structures and around implants [222] during occlusal loading in vitro and in vivo [223] and ex vivo, on cadavers with natural teeth after implant insertion supporting unsplinted and splinted fixed prostheses [224]. Indirect measurements have also been done on mandible replicas made of autopolymerized acrylic resin [224] and epoxy resin [225].

The research was based on the following premise: the degree of bone resorption and periodontal type of splint influence the deformation of the mandibular bone.

The study was conducted in two stages: first, the validation of the mandibular dental arch model, which is the subject of the present article, and second, the evaluation of mandibular bone strain in case of different types of bone loss and periodontal splints, which is the subject of a second article.

I.2.1.1.4.1. Validation of an acrylic resin for the completion of biomechanical studies on a mandibular model

The splinting of teeth with periodontal condition represents a therapeutic mean to achieve functional balance in the complex treatment of periodontal disease. An important aspect in choosing the type of splinting is the mechanical interaction between the employed materials and the dento-periodontal substrate with the supporting bone [226, 227].

There is little information in the literature regarding the impact of bone resorption and periodontal splinting on the biomechanical response. Because of this, the use of splinting and the selection of its type remain a difficult decision for practitioners. In order to quantify these aspects, one can use several methods, each with limitations, advantages and disadvantages: photoelasticity, finite element analysis and resistive electric tensometry [192, 193].

When aiming at creating a mandibular model to simulate different hypotheses and clinical scenarios, a decisive aspect is the selection of the right material able to reproduce the bone substrate. This material must provide mechanical and elastic properties similar to the mandibular bone, as well as a viscosity and a working time appropriate to the model's complexity intended to be achieved.

Katz et al. mention that the bone is not a homogeneous material and its properties will vary according to the age, sex, the type of bone and location [228]. O'Mahony et al. noticed differences between the modules of elasticity in different regions of the mandible [210, 229]. The in vitro studies require the use of an isotropic material with elastic properties similar to the mandibular bone from the region of interest. In this respect, regardless of the chosen method, it is necessary to determine the elastic constants for the employed material, in advance, in order to create the mandibular model.

The literature reports different materials that were studied, aimed at the evaluation of tensions at the level of bone in various situations: acrylic resin, epoxy resin, polystyrene resin, polyurethane resin [193, 222, 225, 230]. The modulus of elasticity is an important elastic characteristic, its values indicating the material rigidity.

Aim of the study

The aim of this study was to validate the use of a self-curing acrylic resin for the completion of a mandibular model in the in vitro studies. To that purpose, the objectives were to determine the elastic constants of the acrylic resin, by studying different situations with varying proportions between the components. The two characteristics, the were determined by means of traction testing. The determination of the two characteristics was performed using resistive electric tensometry. This method enables the high precision measurement of specific longitudinal and transverse strain.

This material will be used to create a mandible replica which will be studied regarding the deformation and tensions by means of resistive electrical tensometry that occurs in the bone mass, in various clinical situations.

Materials and method

a. Obtaining test specimens

25 test specimens were manufactured from acrylic resin (Duracryl Plus, Spofa Dental, Czech Republic, No. lot: 2373741) by pouring in a silicone mould (Fig. 23).

The samples were divided into 5 groups, corresponding to different proportions between the powder and the liquid components and to the polymerization technique (self-curing and heat curing - 50˚C, 15 minutes, 2.5 bars) (Table 26).

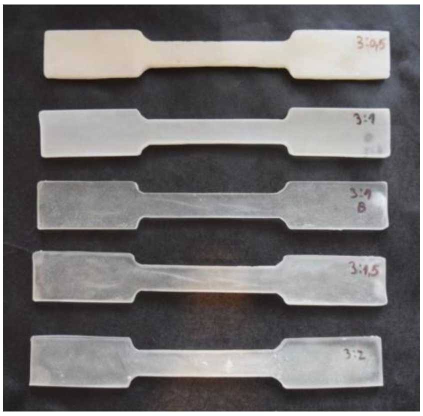


Fig. 23. Test specimens from acrylic resin corresponding to the five groups

Table 26. Test specimens classified into 5 groups

Group	Volumetric ratio powder: liquid	Polymerization technique
A	3:0.5	Self-curing
B	3:1	Self-curing
C	3:1	Heat-curing
D	3:1.5	Self-curing
E	3:2	Self-curing

After manufacturing, the samples were visually inspected in order to detect the presence of potential material defects, as well as the inclusions of air. The final samples were processed to obtain the required dimensions of the recommended testing samples as specified by the STAS SR EN ISO 527-1:2012 standard, describing the traction test [231]. This way, flat testing specimens of rectangular section were obtained. The sample dimensions are: length L = 150 mm, width l = 20 mm and thickness = 3 mm. Each testing specimen presented a calibrated central area with the length L_o = 60mm, width l_0 = 10 mm and increased section end. The two ends were armed with metallic plates that offer the required resistance to the grip area in the stand of the trial machine.

b. Applying the strain gauges

In order to determine the specific deformations, two strain gauges were applied on the testing specimens. The tensometric sensors were selected on the dimensional criteria in order to allow the positioning in longitudinal and in transversal direction.

The employed strain gauges had the following dimensions and resistive properties: 6 mm length, 2 mm width and an electric resistance of 120±0.03 Ω at 24˚C (EA-06-240LZ-120/E, Micro-Measurements Group, Vishay, Nr. lot: R-A59AF524).

For the installation of strain gauges, the following steps were taken:

2. the surface was properly prepared: the degreasing was done with isopropyl alcohol, the abrasion with a paper of granulation 220, the removal of the remaining dust after abrasion and again degreasing;
3. the landmarks for the gauge orientation were drawn;
4. the tensometric sensors were fixed with the cyanoacrylate adhesive Z 70, one in the longitudinal direction, and the second one in the transversal direction (Fig. 24);
5. the tinning of the conductors was performed using a thermostat soldering bit with a proper gluing alloy;
6. the verification of gauges was performed before the measurements were initiated [220].

The measurement of specific deformations provided by the strain gauges was performed using the Wheatstone - Vishay P3 bridge type (Fig. 25) [232].

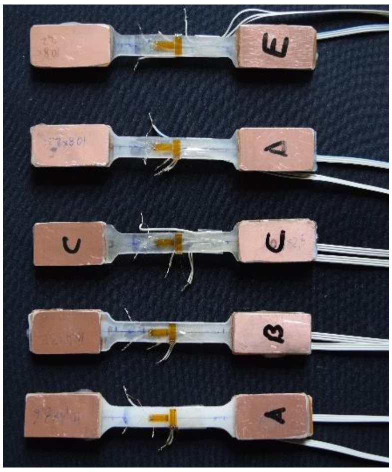


Fig. 24. The test specimens, with metallic plates and strain gauges

Fig. 25. The Wheatstone bridge – model P3, Vishay [13]

a. Mechanical testing

The traction testing was performed on a WDW-5CE computer assisted machine, which can be found at the Laboratory of Mechanical Testing at the Department of Mechanical

Engineering, Mechatronics and Robotics of the Technical University "Gh. Asachi" in Iasi (Fig. 26).The test specimens were fixed between the wedge grips of the machine (Fig. 27). The traction testing of the test specimens was then performed on the machine, with a load speed of 0.5 mm/min, till failure. The static tests were performed at room's temperature (23°C).

The indication of specific deformations given by the strain gauges was done on the Vishay P3 bridge. Signals from the gauges glued to the specimens were obtained and the values of specific deformation in the area and in the direction of the gauge were determined.

b. Calculating the modulus of elasticity and the Poisson's ratio

The data thus obtained was processed in order to determine the values of the elastic constants of the material. Based on this data, the constants of elasticity as slopes of the curve approximation line were determined. Consequently:

1. The longitudinal modulus of elasticity– E (Young modulus) is determined as the approximation line of the graphic represented in the coordinates of normal tension (σ) / specific longitudinal deformation (ε_L), by means of the points determined based on the signals output by the longitudinal strain gauge (Fig. 28). The normal stress was calculated with the relation:

$$\sigma = F/S_0 \qquad (1)$$

where:

σ - normal stress;
F- force of traction;
S_0 - area of the tested specimens transversal section [205].

2. The coefficient of transversal contraction – ν (Poisson's ratio) is determined based on the drawn curve in the coordinates of the transversal specific deformation (ε_T) / longitudinal specific deformation (ε_L), using the signals obtained both from the longitudinal gauge, as well as from the transversal one (Fig. 29).

Results

This study, started with the assumption that the variation of the two components in the manufacture of the acrylic resin would determine different values of elastic constants, different viscosities and different setting times. The initial step considered the proportion indicated by the manufacturer (3:1) with a self-curing technique and next four more mixing variants were evaluated. Another direction focused on the self-curing and on the heat-curing. Table 27 presents comparatively the values of the elasticity modulus and of the Poisson's ratio for the 5 groups.

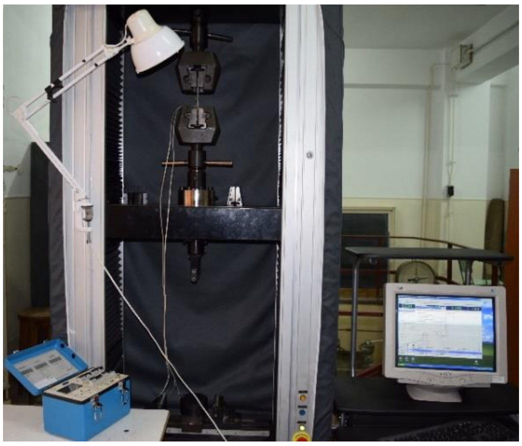


Fig. 26. The testing machine type WDW-5CE and the Wheatstone tensometry bridge

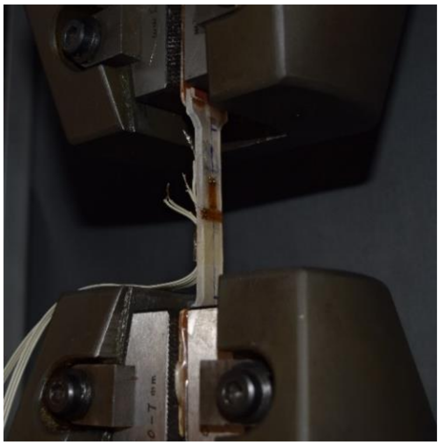


Fig. 27. The positioning of the test specimen between the machine's wedge grips

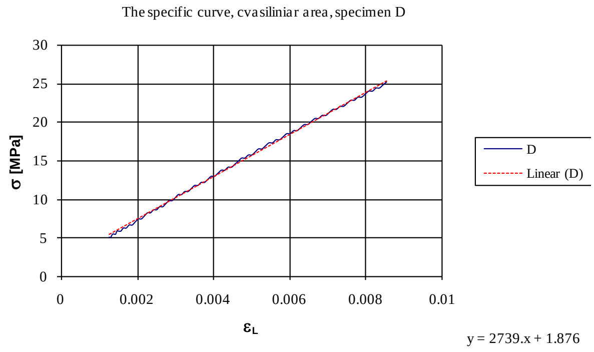


Fig. 28. The variation of normal stress depending on the longitudinal specific deformation

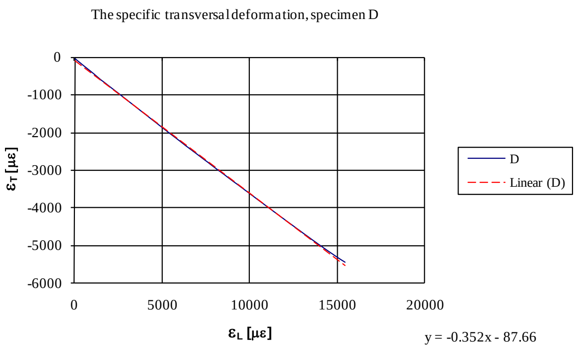


Fig. 29. The variation of transversal specific deformation depending on the longitudinal specific deformation

Table 27. Elastic characteristics of the acrylic specimens (p<0.05)

Group	***Elastic modulus E (MPa)***		***Poisson's ratio***	
	Mean	***SD***	***Mean***	***SD***
A	2461	53.18	0.336	0.06
B	3060	77.06	0.342	0.09
C	3965	157.08	0.349	0.06
D	2739	111.83	0.352	0.05
E	2477	96.80	0.359	0.05

Discussions

The elasticity modulus represents an essential characteristic for the validation of an experimental model. This characteristic differs both between the cortical bone and the spongy bone, as well as among different areas of the mandible.

An important area of interest in the study was the anterior region of the mandible, for which different values of the elasticity modulus and of the Poisson's ratio of the spongy bone are reported in literature: 1.37 GPa / 0.29 - 2.5 GPa / 0.3 [233].

Considering the literature reported elastic parameters of mandibular anterior spongy bone, the results of this study revealed that the specimens of A, D, E groups might be considered as reliable bone substitute in experimental studies.

Considering the aspects relating to preparation, manipulation and setting time of the material, one can make the following considerations:

- in group A, the mixing of the two components was done with difficulty, because of the increased mixture viscosity. This did not allow the pouring of the material into the conformer, but its placement by means of jagging.
- in group D, the mixture of the two components determined a homogenous mixture, having a convenient viscosity. This allowed the pouring into the conformer, with an average setting time.
- in group E, by mixing the two components, a homogenous mixture was also obtained, having a low viscosity, which allowed an easy pouring into the conformer, with an increased setting time, but with the disadvantage of an increased contraction.

Thus, the use of acrylic resin ratio from group D in further experimental studies regarding mandibular model biomechanics was considered adequate.

Conclusions

1. The elastic characteristics of the material varied significantly in relation to the proportion of the components.
2. The volumetric ratio 3 parts powder: 1.5 parts of liquid, presented elastic characteristics like those of the spongy bone from the anterior region of the mandible, as well as an average viscosity. This allows the pouring into complex forms, a proper work time and a low contraction.
3. Taking the obtained results into consideration, the use of this self-curing acrylic resin (3:1.5) can be justified for the manufacturing of experimental mandibular model. This type of mandibular model is suitable for various biomechanical tests, which employ resistive electric tensometry and photoelasticity.
4. The values obtained for the elastic constants will be used in future studies to calculate the tensions that appear in the mandible model and to perform an analysis using the finite element method.

I.2.1.1.4.2. In vitro study regarding the biomechanical behaviour of bone and periodontal splints: model validation

Aim of the study

The research was based on the following premise: the degree of bone resorption and periodontal type of splint influence the deformation of the mandibular bone. The study was conducted in two stages: first, the validation of the mandibular dental arch model, which is the subject of this chapter, and second, the evaluation of mandibular bone strain in case of different types of bone loss and periodontal splints, which is the subject of the next chapter.

Materials and methods

The dumping effect of the periodontium, tooth displacement and bone strain were evaluated with Periotest device, mechanical comparator and strain gauges respectively. Six acrylic mandibular models, each with 8 teeth, were tested for four variables: (i) occlusal load (30N, 50N, 100N, 150 N); (ii) bone status (without and with bone loss); (iii) mandible surface (buccal/lingual aspect of the bone); (iv) load distribution (central incisors and incisal group); (v) tooth (central incisor - CI and lateral incisor - LI).

a. Teeth selection

Forty-eight mandibular teeth, from the first right premolar to first left premolar, were selected, six of each type in order to obtain six mandibular models. Teeth were extracted due to periodontal or orthodontic reasons (the study was conducted with the agreement of the ethics committee of Grigore T. Popa University of Medicine and Pharmacy, Iasi, no. 8670). The selected teeth had the mesial-distal, buccal-oral, and cervical-occlusal dimensions of approximately equal dimensions, accepting a variation of maximum 10% [220].

b. Obtaining the mandibular models

An edentulous human mandible from Human Anatomy Department of the University was used as reference for curvature and position of the teeth, but also for reproducing the anatomy of the anterior part of the mandible. An impression of the mandible was taken with condensation silicone (Zetaplus Putty, Zhermack, batch No. 192139) (Fig. 30) and used as a conformer for mandibular model (Fig. 31). A pink wax modelling roller (Morsa Dental, Germany, Lot No: DM000147VA804) was made using the silicon conformer (Fig. 32). After the insertion of all the teeth, respecting the inclination of longitudinal axes and the interdental contact points, an impression of the coronal part of the teeth was taken with the same condensation silicon to obtain a guide to standardize the position of the teeth (Fig. 33).


Fig. 30. Impression of the mandible


Fig. 31. The conformer for mandibular model


Fig. 32. Teeth positioning according to the arch curvature – buccal vie


Fig. 33. The silicone guide

After the disengaging from the wax roll, the root surfaces were cleaned and covered with a layer of calibrated green wax of 0.3 mm thickness (KARL BERG Dental, Germany, batch no.: 42731313) to replicate the periodontal ligament space (Fig. 34). Then the teeth were inserted into the silicone coronary guide and the roots were isolated using an isopropanol-based substance (Morsa Dental, Germany, lot no.: L2040030-1).

A self-curing acrylic resin was used as material for mandibular bone substrate, with the powder to liquid ratio of 3 to 1.5 (Duracryl Plus, Spofa Dental, Czech Republic, No. Batch: 2373741) [234]. After the acrylate setting, the molten part has been removed from the conformer and then the teeth were removed from the mandibular models and cleaned. Material surpluses were removed and the mandible's external aspect was smoothed using an electric micromotor (Saeyang Marathon Escort III) (Fig. 35).


Fig. 34. Roots covering with a 0.3 mm calibrated layer of wax


Fig. 35. Acrylate mandible model after tooth removal

A fluid condensing silicone (Zetaplus Light, Zhermack, batch No. 192139) was inserted into the dental alveoli to reproduce the periodontal ligament. The teeth were placed in the alveoli and the excess material was removed before the material setting time was over.

c. Selecting and placing the strain gauges

Strain gauges (SG) (EA-06-240LZ-120/E, Micro-Measurements Group, Vishay, Batch No.: R-A59AF524) with 6 mm length and 2 mm width were selected to quantify the deformations of the bone. Their electrical resistance was 120 ± 0.03Ω at 24ºC.

Six strain gauges were applied on each of the six mandibular models, oriented on the coronal-radicular axis: three on the buccal surface (SG 1 - right lateral incisor/RLI, SG 2 - left central incisor/LCI, SG 3 - left canine/LC) and three on the lingual surface (SG 4 - LC, SG 5 - LCI, SG 6 - RLI).

After degreasing and abrasion, the strain gauges were bonded along the long axis of each tooth, at 5 mm apical to the superior edge of the acrylate (corresponding to the alveolar margin) to allow the acrylate milling and simulation of bone resorption. The strain gauges were protected with a polyurethane lacquer (M-coat, Micro-Measurements Group, Vishay, Lot No. 1694). Next, the tensile conductors were connected to the tensiometric transducers, and mechanical and electric verification was done. The final appearance of the samples before mechanical testing is shown in figure 7.

Two strain gauge bridges P3 model (Vishay) were used for recording the specific strains measured by strain gauges (Fig. 37).

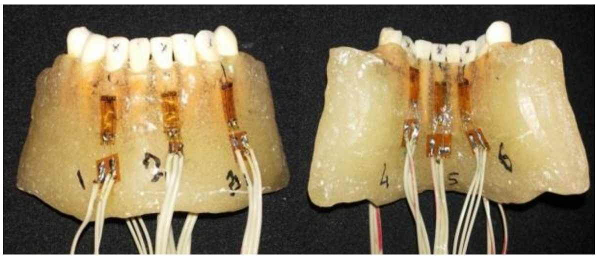


Fig. 36. The final aspect of models after application of the strain gauges (a – buccal view; b – oral view)

Fig. 37. Strain gauge bridges P3 model (Vishay)

d. PERIOTEST method

To verify the accuracy of the periodontal ligament simulation procedure, dental mobility was tested with PERIOTEST (Medizintechnik Gulden, Germany) at the level of each tooth, in the middle of the buccal face, with three values per tooth (Fig. 38).

The 'Periotest value' (PTV) depends to some extent on tooth mobility, but mainly on the damping characteristics of the periodontium [235]. The PTV rang from –8 to +50 and can be correlated with the four classes of tooth mobility reported by Miller [236]. The PTV and its correlations to clinical mobility are given in Table 28.

Initially, the mechanical tests were performed on the original bone model, with normal alveolar bone height (NBH). Subsequently, 5 mm of acrylate was removed for CIs and 4 mm for LIs, replicating the bone resorption (BR) from marginal periodontitis, and new Periotest mobility assessment was performed.

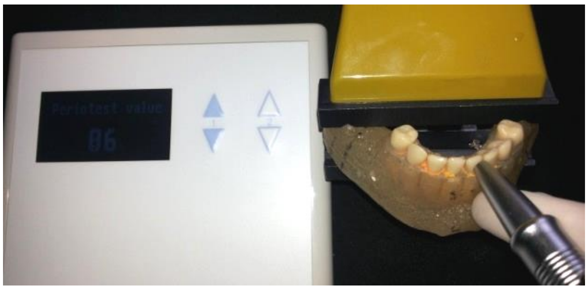


Fig. 38. Verifying the dental mobility with PERIOTEST

Table 28. PTV vs. clinical mobility

Periotest Value	Clinical degree of tooth mobility
(-8) - (+9)	0
(+ 10) - (+ 19)	I
(+20) - (+29)	II
(+30) - (+50)	III

e. Compression test of the initial mandibular models

Compression tests were performed with a WDW-5CE High Performance Electronic Universal Testing Machine (Bairoe, Shanghai, China). With a specially adapted device, the position of the model on the machine table allowed to apply an occlusal load at an angle of 135° to the long axis of the mandibular teeth, simulating the normal interincisal angle (between upper and lower incisors).

Two loading devices were used to simulate mandibular dynamics so that the force was distributed as follows: (i) at the level of the four incisors - 4I; (ii) at the level of the two central incisors - 2I.

Three compression tests were made for each situation. The loading speed was 0.5 mm/min, the maximum load being 150N. The static tests were performed at room temperature (23°C). Before each test, a 5-minute break was made to allow re-calibration of the gauges, and if this was not done, the manual balance of the gauges (zeroing) was used. The time-force variation was recorded on the WDW50 testing machine, and the specific deformations provided by the SG (in relation to time) were made on the Vishay P3 bridges (Vishay Precision Group, Inc.).

f. Teeth displacement evaluation

As mechanical comparator, a dial indicator was used throughout the tests allowing measurements with an accuracy of ± 0.01mm. The plunger was positioned in contact with the middle 1/3 of the buccal face of LCI and RLI (Fig. 39).

The models were subjected to three similar loading cycles and the displacement values expressed in mm were read for the four loading forces: 30N, 50N, 100N and 150N, respectively.

g. Statistical analysis

The collected data were processed with STATISTICA 11.0 (Stat-Soft, Tulsa, OK). The collected strain data was subjected to a factorial analysis of variance (ANOVA) to examine the effect of bone status, mandible surface, load distribution and tooth, and as well as the interaction between these 4 parameters on the strain under 30, 50, 100, and 150 N loading. All tests were performed at a significance level of 0.05.

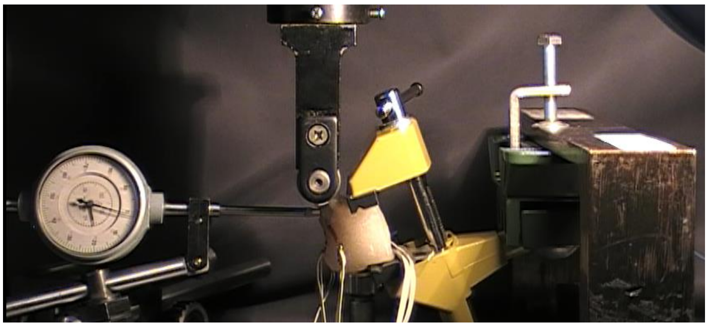


Fig. 39. The probe application on the buccal surface of the lateral incisor

Results

Advanced periodontal disease is characterized by a significant reduction of the periodontal support associated with increased dental mobility [237]. Under these conditions, even the physiological occlusal forces may have a negative impact on the bone support, worsening the bone resorption. Since these aspects cannot be clinically evidentiated, in vitro studies are necessary to quantify the impact of occlusal load and periodontal splinting on alveolar bone. For these reasons, reliable mandible replica is necessary, in order to accurate reproduction of the intraoral biomechanical conditions.

Table 29. The means (standard deviations) of PTVs

Tooth	RP	RC	RLI	RCI	LCI	LLI	LC	LP
Normal bone height	1.0 (0.2)	-1.0 (0.5)	0.2 (0.7)	0.0 (0.3)	0,1 (0.2)	0.2 (0.3)	-0,8 (0.2)	0.1 (0.4)
Bone resorption	1.0 (0.2)	-1.0 (0.5)	27.3 (1.5)	34.7 (2.5)	41.3 (2.5)	28 (2.0)	-0,8 (0.2)	0.1 (0.4)

RP = right premolar; RC = right canine; RLI = right lateral incisor; RCI = right central incisor; LCI = left central incisor; LLI = left lateral incisor; LC = left canine; LP = left premolar

Table 30. Bone strain values for the four compression loads

Load distr.		2I								4I							
Bone status		NBH				BR				NBH				BR			
Surface		Buccal		Lingual		Buccal		Lingual		Buccal		Lingual		Buccal		Lingual	
Tooth		LI	CI	LI	CI	LI	CI	LI	CI	LI	CI	LI	CI	LI	CI	LI	CI
30N	***Mean***	13.0	298.3	9.8	259.9	32.0	547.4	28.1	486.0	91.8	65.2	151.4	109.8	143.5	249.6	110.4	178.4
	SD	1.66	36.91	1.03	31.77	3.90	57.49	3.58	59.61	11.01	8.31	19.17	13.17	18.27	30.01	14.05	22.42
50N	***Mean***	23.0	399.6	16.0	360.6	39.0	730.2	37.0	647.4	123.4	204.8	92.4	153.3	201.8	356.6	156.8	261.7
	SD	2.65	46.02	1.77	41.53	4.49	82.49	4.26	72.84	13.49	23.58	9.91	17.00	23.24	41.07	18.06	30.14
100N	***Mean***	38.4	800.4	23.2	680.4	53.9	1389.7	41.3	1181.7	230.5	421.4	194.4	337.2	364.6	661.1	313.7	540.9
	SD	3.92	90.17	2.36	76.67	6.21	158.09	4.25	134.51	25.48	47.18	21.55	37.91	41.99	74.92	36.13	61.58
150N	***Mean***	48.9	1169.5	37.1	1014.4	64.3	1710.3	52.3	1527.5	329.6	615.7	281.4	509.9	541.7	962.1	471.4	812.8
	SD	5.64	133.41	4.03	114.45	6.86	193.66	5.59	174.01	37.97	70.33	31.38	57.96	61.99	109.05	52.85	92.59

I=incisive; NBH = normal bone height; BR = bone resorption; LI = lateral incisive; CI = central incisive; SD – standard deviation

It was proved that Periotest is a reliable device to evaluate the tooth mobility. The records made with Periotest device proved to be reproducible, with insignificant statistically variations (Table 29). For incisors with bone resorption, PTVs between 27 and 41 units were obtained, which is accordingly to clinical findings and justify the application of immobilization systems. As according to a related study, for in vitro experiments a much smaller measurement error than in in vivo experiments is expected [238]. Clinically, there are too many factors that can influence the PTV measurements.

Table 31. Results of factorial ANOVA for data obtained with the 4 loadings (dependent variable: strain)

		30 N			50 N			100 N			150 N		
	df	SS/MS	F	p	SS/MS	F	p	SS/MS	F	p	SS/MS	F	p
Intercept	1	4330433	5808.89	<.001	8137427	6323.55	<.001	29752770	6396.58	<.001	57938751	6784.33	<.001
LD	1	185709	249.11	<.001	277205	215.41	<.001	738079	158.68	<.001	680489	79.68	<.001
BS	1	338731	454.38	<.001	629043	488.83	<.001	1865246	401.01	<.001	2565536	300.41	<.001
MbS	1	43888	58.87	<.001	70089	54.47	<.001	235670	50.67	<.001	304091	35.61	<.001
T	1	1796174	2409.41	<.001	3307454	2570.21	<.001	12706872	2731.87	<.001	23732673	2778.97	<.001
LD*BS	1	34844	46.74	<.001	35531	27.61	<.001	102873	22.12	<.001	615	0.07	0.789
LD*MbS	1	2428	3.26	0.073	4715	3.66	0.058	2331	0.50	0.480	79	0.01	0.924
BS*MbS	1	2011	2.70	0.103	5221	4.06	0.046	10440	2.24	0.137	4907	0.57	0.450
LD*T	1	851543	1142.27	<.001	1477916	1148.48	<.001	5190947	1116.01	<.001	8744278	1023.91	<.001
BS*T	1	145154	194.71	<.001	274104	213.00	<.001	874412	187.99	<.001	907906	106.31	<.001
MbS*T	1	11947	16.03	<.001	18913	14.70	<.001	98150	21.10	<.001	114171	13.37	<.001
LD*BS*MbS	1	85	0.11	0.737	192	0.15	0.700	672	0.14	0.704	796	0.09	0.761
LD*BS*T	1	76234	102.26	<.001	120660	93.76	<.001	422996	90.94	<.001	338911	39.68	<.001
LD*MbS*T	1	878	1.18	0.280	1008	0.78	0.378	18847	4.05	0.046	17687	2.07	0.153
BS*MbS*T	1	1158	1.55	0.215	3438	2.67	0.105	7009	1.51	0.222	1349	0.16	0.692
1*2*3*4	1	0	0.00	1.000	213	0.17	0.685	2699	0.58	0.448	19	0.00	0.963
Error	128	95422/ 745			164716/ 1287			595373/ 4651			1093131/ 8540		

LD = load distribution; BS = bone status; MbS = mandibular surface; T = tooth; df = degrees of freedom; SS = sum of squares; MS – mean square; F = calculated F

Table 32. Horizontal displacement values at the level of right lateral incisor and left central incisor recorded by the comparator (mm)

Load (N)		Force distribution											
		NBH_{4I}		NBH_{2I}		NBH_{c}		RB_{4I}		RB_{2I}		RB_{C}	
		RLI	LCI	RLI	LCI	RLI	LCI	RLI	LCI	RLI	LCI	RLI	LCI
30	*Mean*	0	0	0	0.01	0	0	0.032	0.05	0.1	0.45	0	0
	SD	0	0	0	0.0018	0	0	0.0024	0.0033	0.0074	0.0615	0	0
50	*Mean*	0.008	0.010	0.002	0.033	0	0	0.21	0.25	0.29	0.95	0.007	0
	SD	0.0013	0.0006	0.0002	0.0041	0	0	0.0352	0.0169	0.0157	0.1463	0.0009	0
100	*Mean*	0.01	0.015	0.003	0.043	0	0.008	0.7	0.96	0.5	1.28	0.07	0.05
	SD	0.0026	0.0009	0.0005	0.0071	0	0.0012	0.0953	0.0887	0.0692	0.3072	0.0055	0.0064
150	*Mean*	0.036	0.040	0.005	0.055	0.002	0.01	1.04	1.17	0.72	1.55	0.16	0.2
	SD	0.0057	0.0033	0.0006	0.0082	0.0003	0.0024	0.0864	0.0230	0.0576	0.1007	0.0332	0.0311

RLI = right lateral incisor, LCI = left central incisor, NBH = normal alveolar bone height, BR = bone resorption, SD = standard deviation

The results for the strains recorded in the bone tissue representing the deformation response of the mandible to occlusal loading are shown in Table 30 and the factorial ANOVA results in Table 31.

Discussions

In a previous study, a self-curing acrylic resin model (Duracryl Plus, Spofa Dental, Czech Republic) used as a replica for the mandible bone was validated [234]. In this respect, the elastic constants of the bone (Young's modulus and Poisson's ratio), essential for simulating an experimental model, were considered.

Various values for the Young's modulus and Poisson's ratio of the trabecular bone in the anterior mandibular region were reported in literature: 1.37 GPa and 0.3 [239, 240], 2.5 GPa and 0.3 [241] and 1.5 GPa and 0.29 [242]. Additionally, different materials used as a replica for mandibular bone in vitro study were reported: acrylic resin, epoxy resin, polyurethane resin, polystyrene resin [224, 230, 236, 243]. For this study, the self-curing acrylic resin used had a volumetric ratio of 3 parts powder to 1.5 parts of liquid and presented elastic characteristics similar to those of the spongy bone from the anterior region of the mandible, as well as an average viscosity. These aspects allowed the pouring into complex forms, a proper work time and a low contraction [234, 244].

Another parameter that required a precise reproduction was the periodontal ligament because it plays an important role in the transmission and distribution of occlusal load in the alveolar bone. The mandibular models used for laboratory studies incorporating materials simulating the periodontal ligament significantly alter the pattern of fracture compared to models without periodontal ligament simulation [245]. In various studies, an attempt was made to simulate the periodontal ligament by covering the roots with a layer of different self-curing materials. Due to lack of standardization, various materials have been used for this purpose: condensation silicones [246, 247], addition silicones [248, 249], polyethers [250-252] and waxes [253]. Sterzenbach et al. have conducted a study on simulation of in vitro dental mobility and compared three impression materials: polyurethane, polyether and polysiloxane. The authors concluded that the most appropriate method of simulation of dental mobility is the use of a self-curing acrylic resin and a polysiloxane [254]. In another study, four materials were compared: two acrylic materials for rebasing - Durabase (Reliance Dental MFG, Co.) and Soft Liner (GC Corporation) and two impression materials - President Plus (Coltene) silicone, Prestige L (Vanini Dental Industry). These were analysed according to two parameters: deformation and return to the initial form. The conclusion was that addition silicone can best simulate the characteristics of the periodontal ligament [255]. In the present study, a fluid condensation silicone was used to reproduce the periodontal ligament (Oranwash, Zermack, Lot No: 192139).

The occlusal forces values are according to the reported data in the literature for the anterior mandible region, between 40 and 200 N [220, 256]. Intermediate loading values (30N, 50N, 100N, 150N) were used to test the influence of small, medium and close loads on the reported physiological limit. Although occlusal forces in the anterior region are usually considered to be relatively smaller, larger forces may also occur in this area, for example, due to the loss of dento-periodontal units in the posterior support region that results in the occlusal forces concentration at the level frontal teeth [199, 257]. The applied forces were non-destructive, falling within physiological limits, the purpose of the study being to quantify deformations at the bone level and not to assess the breaking force and fracture pattern of various dental fixtures.

The clinical relevance of strain values is that they describe the biomechanical behaviour of supporting dental tissue subjected to occlusal forces deformation. Even if they are indirectly determined, on a mandible replica that did not simulate all the live tissues characteristics and did not have the exact same shape and dimensions, these recorded strain values were similar to those reported by Soares et al. [193] and Cehreli et al. [224].

High strains in supporting bone tissue may cause immediate damage to the bone. Even small, cyclically applied forces over a longer period can cause a fatigue phenomenon or interfere with tissue healing processes, also due to the small size of the bone structure in this region. In all simulated situations, higher values of deformations on the vestibular surface were observed, as reported by Soares et al., which can be explained by a lower thickness of the buccal bone versus the lingual bone [193]. Periodontal disease reduces the bone support of teeth leading to increased strain. In this context, even the physiological loads may become harmful. Periodontal splinting contributes to distributing the forces to adjacent teeth, reducing the impact on the already suffering supporting bone tissues. Lowering the induced strain permits the reparatory bone processes to occur in a context of a reduced irritation.

Conclusions

The vitro experiments are generally disregarding the innervations of teeth, the viscos-elastic features of the periodontal ligament, endo-periodontal pathology, the blood, the humidity or other tissue characteristics [225] and the physical properties of the bone could only be partially simulated. These features can be modified by dynamic occlusal load, which is characteristic for oral environment, leading to a different biomechanical behaviour. Our model showed that the loss of bone support and the increasing occlusal loading resulted in significantly greater displacement of the loaded teeth and their adjacent ones, reflecting the clinical findings. The displacement in the central incisor region was significantly higher than in the lateral incisor region. Within the study's limitations, the mandibular replica obtained can be used as a starting point for further biomechanical studies in different dental domains like orthodontics, periodontology and fixed and removable prosthodontics.

I.2.1.1.4.3. In vitro study regarding the biomechanical behaviour of bone, FRC and wire composite periodontal splints: model analysis

While the clinical rational for splinting is less disputable in current scientific literature [258-262], the latest advances in splinting materials and the wide variety available [263] can create confusion among practitioners. There is even less information regarding the biomechanical response of the periodontal complex in the context of different bone resorptions and splints [226, 227]. These aspects make splinting therapy to be a challenging decision for dental professionals.

Aim of the study

The purpose of the study was to evaluate the biomechanical behaviour of mandibular bone by means of electric resistive tensometry method, in case of different periodontal splinting systems subjected to different occlusal forces. The method was described in the first part of this research, in a previous paper [264]. The premise of this research was that the degree of the bone resorption and the type of the periodontal splint influence the tooth displacements and, consequently, the deformation of the mandibular bone, resulted in the recorded strain values.

Materials and methods

a. *Mandibular acrylic models*

The tests were carried out on six mandibular acrylic models (Duracryl Plus, Spofa Dental, Czech Republic, No. Batch: 2373741). The fabrication and validation of the models were previously described in detail [264]. In brief, each model comprised of eight extracted mandibular teeth, from the first right premolar to the first left premolar. The periodontal ligament was replicated with a fluid condensation silicone (Oranwash L, Zhermack, batch No. 192139).

After performing mechanical tests on the initial model with bone integrity (normal height bone - NHB), 5 mm and 4.5 mm acrylate removal was performed on CIs and LIs, respectively, corresponding to bone resorption (BR) in marginal periodontitis. The mobility Periotest values (PTVs) of CIs and LIs were greater than 30 units, which justified the application of periodontal splinting.

b. *Periodontal splints*

The materials used for the periodontal splints are shown in Table 33. *Construct* (Kerr UK Ltd, Peterborough) is an ultra-high strength polyethylene fibre that has been cold gas plasma-treated and is pre-silanated with unfilled resin. *Premise* is a light-cured resin composite containing three different sized filler particles (tri-modal): prepolymerized fillers, 30-50 microns; barium glass, 0.4 microns; and silica nanoparticles, 0.02 microns.

Table 33. Materials used for dental splinting

Material	Producer	Batch no.	Type of material
Construct	Kerr	5102784	Non-impregnated woven polyethylene fibre 2 mm
Construct	Kerr	5100456	Impregnating resin
Premise Packable	Kerr	4957927	Nanofilled restorative composite packable
Premise Flow	Kerr	5123370	Nanofilled restorative composite flow
Wildcat .0195”	Dentsply GAC	171245	Twisted stainless steel wire
OptiBond XTR Adhesive	Kerr	4788988	Adhesive
Pegasus etchant gel	Astek Innovations	1209132	Orthophosphoric acid 37%
Light-curing unit	Woodpecker		Luminous intensity of 1200 mW/cm^2; wavelength of 430-480 nm

The first splinting system was wire-composite resin (WRC). The steps were as follows: (1) measuring the inter-canine distance and cutting the appropriate length of the twisted wire; (2) adapting and conforming the wire on the model; (3) degreasing of lingual surfaces; (4)

etching of lingual and proximal accessible surfaces with orthophosphoric acid 37% for 30 seconds; (5) acid removal, surface washing and drying; (6) applying of the adhesive and light cure for 20 seconds / tooth with the tip of the light beam placed at a distance of 5 mm from the sample; (7) wire positioning and applying of the packable composite layer at the level of each tooth, followed by light curing for 40 seconds / tooth (Fig. 40).

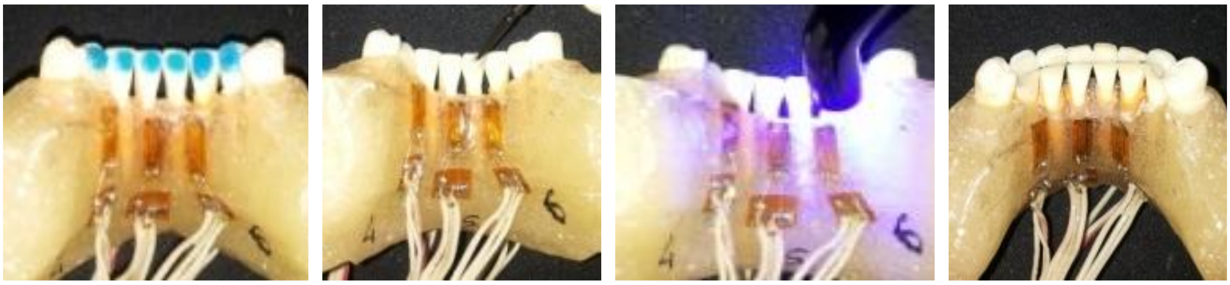


Fig. 40. The steps for applying the wire-composite splint

After performing the mechanical tests on the wire-composite splint model, the splint was carefully removed in order to avoid the damage of the model and of the strain gauges.

The second immobilization system was the polyethylene fibre composite (FC). The steps were as follows: (1) measuring the inter-canine distance and cutting the corresponding strip of fibre band; (2) impregnation of the polyethylene fibre with the Construct resin; (3) degreasing of lingual surfaces; (4) etching of lingual surfaces with orthophosphoric acid 37% for 30 seconds; (5) acid removal, surface washing and drying; (6) adhesive applying and light curing for 20 seconds / tooth; (7) applying of a 0.2 mm layer of Premise composite; (8) adapting the impregnated polyethylene fibre and removing the excess of composite; (9) light-curing for 40 seconds / tooth; (10) applying a final layer of Premise flow composite to fully covering the fibre and light curing for 40 seconds / tooth (Fig. 41).

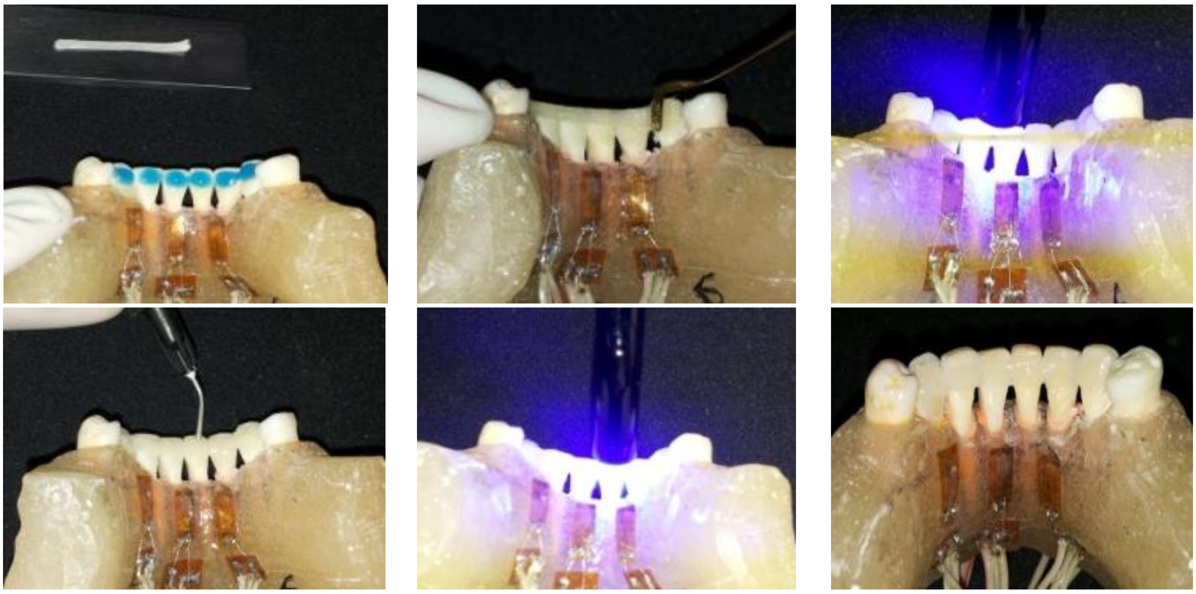


Fig. 41. The steps for applying the polyethylene fibre composite splint

c. *Mechanical testing of the samples*

The mechanical testing protocol was also described in detail in the first part of this study [264]. It is presented briefly below.

6 mm length and 2 mm width strain gauges (SG) (EA-06-240LZ-120/E, Micro-Measurements Group, Vishay, Batch No.: R-A59AF524) were selected for quantifying the bone deformation. Their electrical resistance was 120 ± 0.03Ω at 24ºC. They were placed on the mandibular replica, corresponding to coronal-radicular axis as it follows: three on the buccal surface (SG 1 - right lateral incisor/RLI, SG 2 - left central incisor/LCI, SG 3 - left canine/LC) and three on the lingual surface (SG 4 - LC, SG 5 - LCI, SG 6 - RLI). A WDW-5CE High Performance Electronic Universal Testing Machine (Bairoe, Shanghai, China) was used to perform the compression tests and record the time-force variation. With a specially adapted device, the model was mounted on the test machine allowing an occlusal load orientation of 135° on the mandibular incisors that replicated the normal interincisal angle, and an individual loading on incisors and canines.

The load distribution was at the level of: (i) four incisors - 4I; (ii) two central incisors - 2I; (iii) canine - C. The samples were three times tested for each load distribution, with a load speed of 0.5 mm / min, 150 N maximum load, at room temperature (23° C) and with a 5 minute break before each test to allow for recalibration of the marks. The specific deformations provided by the strain gauges (in relation to time) were recorded with two strain gauge bridges P3 model (Vishay). The displacement values were read for the four loading forces: 30 N, 50 N, 100 N and 150 N, respectively.

A dial comparator was positioned in contact with the labial middle third of RLI, which allowed the horizontal tooth displacement measurements with an accuracy of ± 0.01 mm (Fig. 42).

The experimental groups were defined corresponding to the bone condition and splint type as it follows: models with normal height bone (NHB); models with bone resorption without splint (BR); models with bone resorption and wire-composite splint (WRC); models with bone resorption and polyethylene fibre-reinforced composite splint (FRC). Each sample was subjected to three similar loading cycles, the force being applied successively on 4I, 2I and C, and the specific deformation values expressed in με (equivalent to μm/m) were read for four loading forces: 30 N, 50 N, 100 N and 150 N.

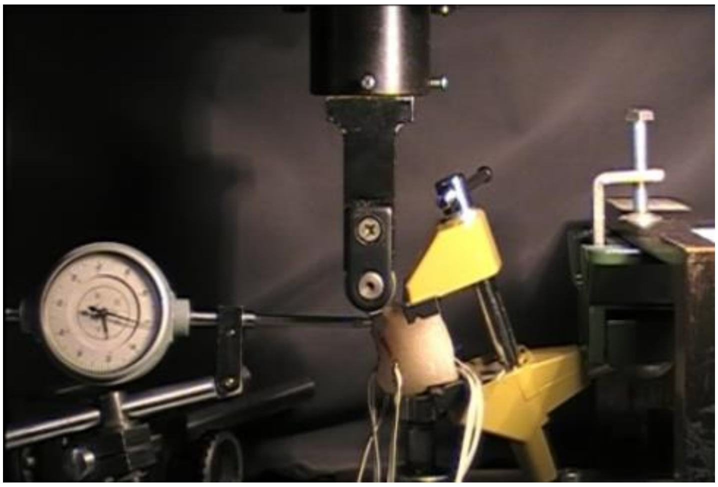


Fig. 42. Positioning the model on the machine support

d. Statistical analysis

Statistical data analysis was performed with STATISTICA 11.0 (Stat-Soft, Tulsa, OK), at a significance level of 0.05. Factorial analysis of variance (ANOVA) was employed to evaluate the effect of four variables: bone condition and splint type (BC), mandibular bone surface (BS), load distribution (LD), and tooth position (T) on the bone strain in the context of different occlusal loading.

Results

The dental mobility was re-evaluated after applying each immobilization system and the results are presented in Table 34. The horizontal displacement values of RLI are presented in Table 35. Bone strains values expressed in με (equivalent with μm/m) for every situation referred above were read for the four forces 30N, 50N, 100N and 150N (Table 36).

Table 34. The means (standard deviations) of PTVs on the model with bone resorption and splint

Tooth	RP	RC	RLI	RCI	LCI	LLI	LC	LP
BR	1.0 (0.2)	-1.0 (0.5)	27.3 (1.5)	34.7 (2.5)	41.3 (2.5)	28 (2.0)	-0,8 (0.2)	0.1 (0.4)
WRC	1 (0.2)	-0,8 (0.3)	2 (0.1)	3 (0.3)	4 (0.2)	3 (0.4)	1,1 (0.4)	0,1 (0.1)
FRC	1 (0.2)	-1 (0.2)	1,6 (0.2)	2 (3)	3,4 (0.1)	0,4 (0.0)	0,8 (0.2)	0,1 (0.0)

RP = right premolar; RC = right canine; RLI = right lateral incisor; RCI = right central incisor; LCI = left central incisor; LLI = left lateral incisor; LC = left canine; LP = left premolar; BR = bone resorption, WRC= wire-composite splint; FRC = fibre-reinforced composite splint [25].

Table 35. The horizontal displacement values of RLI (mm)

Load (N)		NHB			RB			WRC			FRC		
		4I	2I	C	4I	2I	C	4I	2I	C	4I	2I	C
30	*Mean*	0	0.01	0	0.05	0.45	0	0.01	0.02	0	0	0.05	0
	SD	0	0.0005	0	0.0035	0.045	0	0.0014	0.0028	0	0	0.0025	0
50	*Mean*	0.01	0.033	0	0.25	0.95	0	0.02	0.04	0	0.013	0.035	0
	SD	0.002	0.006	0.000	0.053	0.238	0.000	0.000	0.001	0.000	0.002	0.006	0.000
100	*Mean*	0.015	0.043	0.008	0.96	1.28	0.05	0.045	0.051	0.01	0.018	0.045	0.01
	SD	0.003	0.006	0.000	0.030	0.143	0.000	0.001	0.006	0.000	0.002	0.006	0.000
150	*Mean*	0.040	0.055	0.01	1.17	1.55	0.2	0.03	0.066	0.025	0.028	0.06	0.015
	SD	0.002	0.007	0.001	0.176	0.388	0.044	0.006	0.009	0.001	0.002	0.013	0.003

I=incisor; C = canine; NHB = normal height bone; BR = bone resorption; WRC = wire-composite splint; FRC = fibre-reinforced composite splint; SD = standard deviation

The factorial ANOVA indicated significant differences between the four factors (load distribution, bone condition, bone surface, tooth; $P < 0.001$), irrespective of load level. For the 2-factor interactions, the following interactions were significant for all load values ($P < 0.001$): bone condition and load distribution, bone condition and tooth, load distribution and tooth, and bone surface and tooth. Of the 3-factor interactions, only the bone condition, load distribution, and tooth interaction were statistically significant irrespective of load level.

Discussions

Static tests with maximum compressive force values of 150 N were performed. The models were subjected to three similar test cycles for each of the above-mentioned situations and the deformation values for four values of the force (30 N, 50 N, 100 N and 150 N) were recorded. These values were chosen because the literature data reported occlusal forces in the anterior mandible region between 40 and 200 N [193, 256]. The purpose of the study being bone deformation quantification and not fracture resistance of splints, intermediate physiological loading values were used. These values might not describe some particular situations when splints are subjected to much larger forces due to lateral edentulism and consecutive occlusal forces concentration in frontal dental area [199].

Deformations values in the anterior region of the mandible were directly proportional to the load values of the four forces. Even small forces applied cyclically over a period of time, can cause a phenomenon of fatigue or interfere with tissue healing processes, taking into account the small size of the bone structure in this region. In all simulated situations, higher values of deformations were observed on the buccal surface, aspect also reported by Soares et al. This can be explained by a smaller thickness of the labial bone compared to lingual bone [193].

Table 36. Bone strains values (με) for the four compression loads

Force	Group	Contact	SG 1		SG 2		SG 3		SG 4		SG 5		SG 6	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
30	NHB	4I	92	10.12	151	6.04	15	0.30	13	2.99	110	16.50	65	8.45
		2I	13	2.99	298	53.64	10	0.60	9	0.99	260	7.80	10	2.00
		C	21	5.04	30	3.00	557	44.56	532	15.96	22	5.50	13	0.65
	BR	4I	143	20.02	250	50.00	16	4.00	13	2.21	178	35.60	110	4.40
		2I	32	5.44	547	54.70	12	1.20	10	0.70	486	68.04	28	2.52
		C	20	4.00	31	2.48	579	115.80	561	22.44	22	4.62	10	0.40
	FRC	4I	102	20.40	150	19.50	35	5.95	31	4.96	108	3.24	66	13.86
		2I	66	15.84	191	30.56	33	5.94	30	6.30	180	28.80	48	6.72
		C	80	3.20	110	12.10	534	85.44	518	62.16	100	17.00	70	3.50
	WRC	4I	91	10.01	149	5.96	32	1.60	28	3.92	108	8.64	64	10.88
		2I	58	4.06	187	35.53	28	5.88	27	3.51	166	6.64	47	7.05
		C	95	7.60	114	25.08	540	10.80	525	10.50	105	15.75	87	9.57
50	NHB	4I	123	30.75	205	12.30	17	3.40	14	2.10	153	16.83	92	21.16
		2I	23	4.83	400	88.00	10	1.60	10	2.20	361	14.44	16	2.56
		C	29	4.06	34	1.70	689	144.69	673	94.22	26	2.34	17	2.89
	BR	4I	202	46.46	357	24.99	18	1.26	14	0.56	262	10.48	157	12.56
		2I	39	8.19	730	87.60	14	0.98	11	0.66	647	161.75	37	6.66
		C	31	4.65	47	6.58	715	21.45	702	56.16	32	5.12	19	2.28
	FRC	4I	131	13.10	229	20.61	54	3.78	43	9.03	162	34.02	101	6.06
		2I	88	11.44	314	69.08	49	9.80	43	8.60	273	8.19	65	13.65
		C	107	18.19	131	9.17	665	139.65	634	19.02	120	10.80	98	14.70
	WRC	4I	126	10.08	203	26.39	53	2.65	41	8.61	151	24.16	90	5.40
		2I	85	19.55	303	60.60	46	10.58	40	5.60	259	5.18	62	7.44
		C	113	24.86	134	30.82	670	26.80	642	25.68	125	5.00	105	22.05
100	NHB	4I	230	9.20	421	29.47	19	1.33	15	2.70	337	6.74	194	27.16
		2I	38	1.90	800	200.00	12	2.88	13	2.73	680	47.60	23	1.38
		C	35	4.90	40	0.80	982	206.22	964	134.96	32	7.04	19	0.95
	BR	4I	365	47.45	661	125.59	21	2.52	18	1.08	541	129.84	314	47.10
		2I	54	13.50	1390	97.30	15	2.40	15	1.65	1182	130.02	41	6.56
		C	41	6.15	49	2.45	1019	203.80	989	49.45	39	7.80	25	4.50
	FRC	4I	244	12.20	452	40.68	81	3.24	77	6.16	340	34.00	238	40.46
		2I	129	25.80	608	91.20	79	6.32	64	10.24	574	74.62	92	2.76
		C	130	5.20	162	37.26	913	219.12	896	107.52	131	13.10	83	8.30
	WRC	4I	237	52.14	405	60.75	80	4.80	75	5.25	327	45.78	195	46.80
		2I	131	9.17	588	99.96	74	9.62	61	10.98	565	107.35	93	22.32
		C	139	27.80	173	25.95	921	119.73	904	117.52	138	5.52	88	2.64
150	NHB	4I	330	36.30	616	73.92	21	2.31	16	3.52	510	45.90	281	50.58
		2I	49	9.80	1170	152.10	12	0.36	14	0.84	1014	233.22	37	8.88
		C	44	4.40	52	9.36	1287	102.96	1279	217.43	48	12.00	34	7.48
	BR	4I	542	59.62	962	192.40	23	5.52	20	2.60	813	186.99	471	108.33
		2I	64	10.24	1710	51.30	17	2.38	16	2.40	1528	229.20	52	6.24
		C	52	9.88	59	2.95	1321	66.05	1294	38.82	48	10.56	36	3.60
	FRC	4I	362	28.96	664	33.20	110	18.70	91	2.73	548	98.64	401	84.21
		2I	148	23.68	910	118.30	92	16.56	88	3.52	782	132.94	123	17.22
		C	193	17.37	215	30.10	1204	108.36	1183	260.26	180	19.80	162	30.78
	WRC	4I	329	19.74	610	73.20	110	23.10	82	16.40	508	66.04	282	50.76
		2I	154	12.32	915	100.65	89	19.58	87	20.88	779	54.53	134	33.50
		C	201	28.14	223	33.45	1215	36.45	1189	35.67	192	26.88	173	15.57

I=incisor; C = canine; NHB = normal height bone; BR = bone resorption; WRC = wire-composite splint; FRC = fibre-reinforced composite splint; SG = strain gauge; SD – standard deviation

It was noticed that, regardless of the value and of the loaded area, strains in group BR were significantly greater than strains in the group NHB, and those in groups WRC and FRC had intermediate values, but closer to NHB group. In addition, strains at the central incisor were higher by 60-85% than at the lateral incisor, except when the contact was made on the canine.

Comparing the BR to NHB groups, a severe increase of strains was observed, both on lingual and labial surfaces, the highest difference (73%) was recorded for 100N force, on buccal for central incisor in BR_{2I} group.

It can be noticed that in the groups with periodontal splinting (WRC and FRC), occlusal forces were distributed to all tooth in the splint, as demonstrated by the modified strain values.

Another quantified parameter with clinical relevance is the tooth contact. When the force is applied to the central incisors, the strains values are 60% higher than when force is balanced applied at the four incisors.

Another interesting aspect is that when force is applied to the incisors, bone strains in FRC group were higher than in WRC group with no significant differences. This suggests a more elastic behaviour of polyethylene fibres than of the wire-composite system.

When contact was at the canine, comparing the distribution of bone strains from the canine, it was observed that in WRC group the strains were higher by 18 % compared with FRC group, regardless of the force. Due to the intern stiffness of the wire, a reduction in incisors strains can be achieved, which has as disadvantage the consecutive increase of canine strain. In the context of constant overloading, the adaptive level of canine support tissues may be exceeded, thus favouring the progression of bone resorption.

Differences between wire-composite splint and fibre-reinforced composite splints may occur also from clinical behaviour point of view. Thus, the wire - composite resin splint has an interface between two materials with different modules of elasticity (stainless steel and composite resin) without chemical adhesion. Thus, in this area fracture initiation may occur because the splint exhibits low fatigue strength [203, 226].

Regardless the contact between the loading device and the dental surfaces, higher values are observed to lateral incisor in the group BR, versus group NHB, for all four forces. For groups WRC and FRC, horizontal displacement value decreased, but remained higher than in NHB group regardless of force level. No significant differences of displacement values were observed between the two splinting groups. The displacement values in the group BR_{2I} were higher up to 300% compared to BR_{4I}, which reinforce the need of balanced occlusion in order to achieve multiple contacts on the four incisors for an even distribution of occlusal forces.

In a study by Soares et al. [193], based on electric tensometry method, the bone strains were compared when adhesives splinting systems (composite resin, wire resin and fibre-reinforced composites) and wire splinting were applied. The authors noted that bone strains values in case of wire splinting were significant higher compared with the FRC splinting. To a force of 150 N, the wire did not achieve significant stabilization of mobile teeth. According to these results, the use of the wire without application of a composite resin and an adhesive system is not suitable in the splinting periodontal treatment. In the same study, the authors pointed out that dental splints with adhesive system and composite resin produced lower bone strains irrespective of occlusal load.

The results obtained should be interpreted in the context of the limitations of this study. The tests were performed in vitro so that all parameters of the bone and dento-periodontal substrate could not be reproduced: cortical bone and spongy bone, different bone densities, vascularization, dental innervation, viscoelastic properties of the periodontal ligament [223]. Clinically, other factors as frontal edentulism, employed materials [190], modified prosthetic values of the teeth [237], surface quality of the restorations and teeth [191, 265-267] can influence the biomechanical performance of the splinting system. Also, the compression tests were static without simulating the cyclic, repetitive loads exerted in the oral cavity.

Conclusions

1. For the groups with periodontal splinting, horizontal displacement values were reduced, but remained higher than in the group with normal bone.
2. Regardless of the load values and distribution, strains in BR group were significantly greater than strains of NHB group and the groups FRC and WRC had intermediate values, but closer to the BR group.
3. In case of bone loss, the bone deformations are up to 110%, regardless of the load value and distribution. Periodontal splinting redistributes forces, reducing incisors bone strains associated with a slight increase in canine bone strains.
4. When a force was applied to the incisors, bone strains in the group FRC were higher than in the group WRC with no significant differences. When force was applied to the canine,

regardless of the force value, canine bone strains were higher by 18 % in the WRC compared with FRC group.

5. Periodontal splinting must be correlated with a balanced occlusion, to allow occlusal forces to be applied to an enlarged area, on the four incisors, which allows a strain reduction up to 63% compared to the situation in which the force is applied only on central incisors.

2.2.2. BIOMECHANICS OF FRC AS PROSTHODONTIC RESTORATIONS

2.2.2.1. State of the art

The treatment of the single tooth edentulous areas still represents a true challenge from several points of view: biological, prophylactic, biomechanical, ergonomic and socio economical.

Different indirect restorations used to replace a single missing tooth are available in dentistry: implant supported crowns (ISC), traditional full-coverage fixed dental prostheses (FDP), inlay or onlay-retained FDPs (or with other types of retainers), and resin-bonded fixed partial denture. The materials used in these restorations are cast metal, ceramics and, more recently, composites.

In oral biomechanical conditions, frequent technical failures occur, such as: loss of retentions, fracture or chipping of veneering, and fracture of framework materials. These complications are directly related with the imbalances between oral biomechanical stress and material properties [170, 268].

Consequently, a framework and veneering materials with correlated and lower modulus of elasticity than that of ceramics or metal alloys, but similar to dental structures, might be useful to reduce the chipping of veneering material and the debonding of the restoration. Therefore, new materials were subjected to tests in oral environment. Fibre-reinforced composites fixed dental prostheses (FRC-FDP) were developed as a necessity of minimal-invasive, reliable and low-cost prosthetic restorations.

The most common dental composites are particulate filler composites (PFC), consisting of a resin matrix (continuous phase) and fillers (particles of various materials and size). The glass fibres as fillers for composite resin matrix were used in the earlier version of today's FRC (short fibres). When fibres are used to reinforce dental composite (continuous long fibres) the resulting material is both a particulate and a laminate composite and is termed a fibre-reinforced composite [269]. Hence, fibre-reinforced composites can be classified into two types: discontinuous short fibres and continuous aligned fibres with anisotropic properties. The reinforcing component provides strength and stiffness, and the matrix supports the reinforcement and provides workability. The most often applied fibres in dental practice are: glass fibres, carbon fibres and synthetic fibres like aramid and polyethylene.

The fibres are the constituent that confers strength properties to various stresses. Compared to the matrix, the maximum stress to which the material can hold is far superior and at the same time the elongation is diminished. The matrix shows a greater elongation and a higher strength that ensures that the fibres break before the entire matrix fails. In areas subjected to high stress, the used restorative materials should have high flexural strength, high elastic modulus and low deformation as well as high impact and fatigue resistance [173]. We emphasize however that the composite material is a unitary system in which the two phases work together as the elongation-effort diagram suggests. Additionally, their modulus of elasticity can be modified, adjusting the fibre/matrix ratio, location and orientation of the fibres. Considering this aspect, the fibre reinforced composites (FRCs) should minimize the stress level at the tooth-restoration interface and improve the biomechanical properties of the pontic and of the retainers [175].

In fixed prosthodontics, fibre reinforced composites are used for [270]: inlay/onlay, full coverage crown, provisional restorations for the period of the implant osseointegration, dental bridge, surface retained bridge, inlay/onlay bridge, full cover crown bridge, hybrid bridge which presents two or more different attaching elements: surface retained blade or wing, inlay, onlay, full cover crown.

As contraindications of selecting fibre reinforced composites [160] the following were enounced:

- inability to maintain good fluid control: patients with gingival inflammation or when the margins should be placed deeply into the sulcus
- long-span prostheses: two or more pontics. (maximum pontic span of 15 mm)
- patients who exhibit parafunctional habits, like bruxism, because there is an increased risk of fracture
- patients who have opposing unglazed porcelain.

The followings are among the advantages of FRCs [160, 166, 173]:

- aesthetic aspect comparable to ceramic, translucency.
- biocompatibility with oral tissues and inessential toxicity
- adequate mechanical properties
- do not abrade or fracture the opposing teeth as ceramic does
- in the aspect of fatigue strength, is stronger than typical cast metal alloys
- preserving tooth substance, because the preparations are minimally invasive in contradistinction to metal-ceramic and all ceramic techniques
- good bonding properties: direct chemical bonding with no need of mechanical retention
- less extensive work by the dental technician
- potential for chair side fabrication, so there is no need for laboratory stages. In this manner it can be approached a prosthetic emergency (the absence of an incisor resulting from trauma) and the tooth can be replaced in a single visit
- ease of repair when veneers fracture occurred
- the pontic can be made from the extracted teeth
- no corrosiveness.

As disadvantages focused on clinical problems, one can mention [160]:

- there should be proper conditions for isolation, in order to assure a good adhesion
- gray show through of metal posts and cores on abutment teeth
- loss of surface luster on the particulate composite veneer
- excessive translucency in pontic area
- transitory sensitivity after cementation
- can appear fracture of the composite veneer
- debonding.

In testing the mechanical behaviour of FRC systems, many different materials and methods were employed [173]. Consequently, the results obtained from the comparison between different methodologies were shown to be inconsistent, especially when different specimen dimensions, fibre thickness, location and orientation are considered [207, 271-273].

Our research was carried out within an internal grant and encompassed several experimental investigations on the fiber-reinforced composite dental bridge, aiming to understand its quasi-static mechanical behaviour, and focused on: (1) quantifying the deformations of the bridge structure – for different methods and different aspects and amplitudes of the pontic; (2) determining the failure load, failure deflection and failure location – in static and dynamic solicitations; (3) identifying the role of the fibers – as quantity, type and position; (4) exploring the effects of the retainers – as position and surface contact with the teeth, marginal adaptation and debonding; and (5) exploring the effects of adjacent teeth – with and without physiologic resilience; (6) analyzing the fracture surfaces of materials by fractographic methods. The experimental results were compared with the clinical observations in order to devise new reliable solutions for recorded failure types.

In nowadays dentistry, the minimal invasive concept is the fundamental basis for any treatment approach [274]. From this perspective, the treatment of partial reduced edentulism might be a challenge. The persistence of any edentulism will lead to malocclusion and TMJ disorders which will complicate the long-term prognosis and the therapeutic solution.

The available means for replacing a missing tooth are: implant supported crowns (ISC) and fixed partial dentures (FPD). The materials used in these restorations are cast metal, ceramics and, more recently, composites. The ISCs are reported to have a 5-year survival rate of 95.1% and a 10-year survival rate of 90%. However, the decision-making process for using of implant-supported prostheses is still, in certain cases of partial edentulism, an important topic of discussion [275]. Furthermore, multiple appointments, reluctance to surgery, temporary restorations, and costs make these procedures often inaccessible to many of our patients.

The traditional FDPs are reported to have a survival rate of 87.7% at 5 years and even 89.2% at 10-years in the situation of natural teeth [268]. As an alternative to metal infrastructure, glass-infiltrated alumina ceramics were introduced at the beginning of 1990s. The 10-year survival rate was reported to be 73.9% for 2-retainer FDPs and 94.4% for single-retainer FDPs [276]. Both need an important sacrifice of dental structures. The FPD are predominantly the full-coverage type, employing the sacrifice of 63 – 73% of coronal dental tissue to prepare for a full crown [277].

For the sake of the minimally invasive concept, the retainers have been modified and new designs for retainers were introduced (inlay, onlay and inlay-onlay) which require a less invasive preparation. In parallel with the reduction of the contact area, the chemical/micromechanical adhesion has been introduced and the luting and bonding systems were constantly improved. The inlay-retained fixed partial dentures are reported to have a 5-year survival rate of 57% and an 8-year survival rate of 38% for IPS E.max Press (IvoclarVivadent AG) [278]. However, all these restorations have disadvantages like debonding, fracture and marginal leakage.

Many patients with partial reduced edentulism refuse the idea of sacrificing healthy teeth in order to restore the dental arch and others don't have the means to accept implants or ceramic resin-bonded restorations. In these cases, fibre-reinforced composite (FRC) bridges constitute a very suitable alternative contributing to the increase in life-quality. The patients can benefit from a system that is minimal invasive and accessible. However, the survival rate of FRC FPD is reported to be 73.4% at 4.5 years, the existing architecture of these bridges needing improvements [177].

Although fibre reinforced composite bridges can be currently regarded as niche restorations due to their specific and limited indications, they carry a great potential at affordable prices and could become the therapy of choice once the possibilities and limitations of these restorations are clearly defined. The rich volume of clinical information on fibre reinforced composite bridges has enabled the utilization of a variety of systems which are different in method (direct/indirect/direct indirect), materials (various fibres and composite types), design and structure, applied in different clinical situations.

Choosing adequate materials for a FRCB proves to be a difficult task, requiring extensive data and experience. The large choice of available materials and the wide range of properties make the task of selecting the right materials to be dependent on an extended study of properties and interactions.

Most of the biomechanical studies performed on fibre reinforced composites for fixed partial dentures focus on the static testing of samples having ISO standard sizes. Also, most of the studies stop here. There are very few studies that use data resulted from sample testing in mathematical simulations or on physical models [212, 279]. Even fewer studies perform a clinical validation of the innovative technological solutions.

At the same time, mechanical tests on bridges of these materials are insufficient, considering the wide variety of systems, aims and employed methods [157, 209].

	Most relevant personal scientific contributions in this field (the highlighted papers are presented in extenso in the next chapters):
ISI	1. Țănculescu O, Ifteni G, Mocanu RM and Doloca A. *Biomechanical behavior of fibre reinforced composite dental bridges*. Materiale Plastice 2011;48(4):332-5 http://www.revmaterialeplastice.ro/Article_ro.asp?ID=3178
	2. Țănculescu O, Doloca A, Vieriu RM, Mocanu F, Mârțu S, Iovan G, Ifteni G, Ioanid N. *Physical and mechanical characterization of different fibre-reinforced composite systems used in fixed prosthesis*. Revista de Chimie 2016; 67(1):96-102. https://revistadechimie.ro/Articles.asp?ID=4819
	3. Țănculescu O, Doloca A, Vieriu RM, Mocanu F, Ifteni G, Vițalariu A, Solomon S, Ioanid N, Iovan G. *Load-Bearing Capacity of Direct Inlay-Retained Fibre-reinforced Composite Fixed Partial Dentures with Different Cross-Sectional Pontic Design.* Revista de Chimie 2017; 68 (1), 94-100 https://www.revistadechimie.ro/Articles.asp?ID=5397
IDB	1. Mocanu RM, Țănculescu O*, Ifteni G, Andronache M, Apostu A, Iordache C, Mârțu S. *Possibilities and limits of fibre reinforced composites in fixed prosthodontics.* Romanian Journal of Oral Rehabilitation, 2012, 4(3):74-77, ISSN 2066-7000 http://www.rjor.ro/revista/2012/numarul-3-2012?lang=ro
Grant	*Evaluation of biomechanical behavior of fibre-reinforced composite bridges* - Internal Grant of "Grigore T. Popa" University of Medicine and Pharmacy Iasi - Contract no. 30880 / 30.12.2014; 01.01.2015 - 30.06.2016 - Project director

2.2.2.2. Physical and mechanical characterization of different FRC systems used in fixed prosthodontics

Aim of the study

The aim of this study is to assess the flexural strength and the flexural modulus of two fibre reinforcement systems with different cross-sectional design. The systems architecture is also referred to as cross-sectional arrangement or design [280].

Materials and method

In the context of using the same packable microhybrid composite (Filtek Z250, 3M ESPE) two different brands of fibre reinforcing products in ribbon-form and pre-impregnated were used in the study: Construct (Kerr) and Dentapreg (ADM) (Table 37).

The evaluated parameters, related to the cross-sectional design, were: (1) different types of fibres reinforcement - glass and polyethylene, (2) different architecture of the fibres - unidirectional and braided, (3) different widths of the fibre - 2 and 3 mm and (4) different position of the fibre. Details of the materials used in this experimental study are given in Table 37.

Table 37. Materials used in the study

Product	Manufacturer	Geometrical parameters	Type of material and chemical composition	Batch number
Construct	Kerr Corporation, Orange, CA, USA	2mm	Ultra-high strength, cold gas plasma-treated silanated biaxial braided polyethylene fibres	5137531
		3mm		5137532
Dentapreg PFM	ADM A.S., Brno, Czech Republic	3 x 0.3 x 60 mm ~ 10700 fibres	Multidirectional (braided) E-glass fibre	03-022014
Dentapreg PFU		2 x 0.3 x 60 mm ~ 8400 fibres	Unidirectional S2-glass fibre	02-022014
Construct Resin	Kerr Corporation, Orange, CA, USA	-	Fumed silica, grounded barium alumina-borosilicate, dimethacrylate resins, silane	4823032
Filtek Z250	3M ESPE, St. Paul, MN, USA	-	Microhybrid composite BIS-GMA, UDMA, BIS EMA	647812
Zetaplus	Zhermack, Badia Polesine, Italy	-	Polysiloxane condensation silicon	158882

Table 38. The specimens divided in 21 groups according to the type and the width of the fibre

Group (n=5)			1	2	3	4	5	6
	Filtek Z250 (Control)	F						
A	Filtek Z250+ Construct 3 mm		C3T	C3C	C3H	C3V	C3U	
B	Filtek Z250+ Construct 2 mm		C2T	C2C	C2H	C2V		C2D
C	Filtek Z250+ Dentapreg 3 mm		D3T	D3C	D3H	D3V		
D	Filtek Z250+ Dentapreg 2 mm		D2T	D2C	D2H	D2V		D2D
		Control	*Tension*	*Compres-sion*	*Middle Horizontal*	*Middle Vertical*	*U-shape*	*Double*

a. *Specimen preparation*

Four main categories of five (n=5) ISO Standard 4049/2000 [281] specimens were created, according to the fibre reinforcement type and dimension (Table 38). A polysiloxane condensation silicon mold was used. The mold was obtained after impression record of a rectangular stainless steel bar-shape specimen of 2 x 2 x 25 mm standard size [190].

The tested specimens for the groups *Control*, *Tension*, *Compression*, *U-shape and Double* were constructed placing first the fibre in polysiloxane mold followed by the composite, slightly pressed against the fibre using a glass slide, with a polyester film interposed between the glass and the mold. For the 3 mm fibres, their fitting into a 2 mm sample width changes the initial disposition of the fibre within the fabric; the fibres in the ribbon are getting closer to each other and they become more oriented in longitudinal direction related to the longitudinal axis of the sample.

For the *U-shape* group, the braided fibres were placed against the bottom and lateral walls of the mold. This type of placement changes the initial disposition of the fibre within the fabric; the fibres in the ribbon spread out and separate from each other and become more oriented in transversal direction related to the longitudinal axis of the sample. For the *Double* groups, two layers of 2 mm fabric were placed on the bottom of the mold.

The tested specimens for the groups *Middle horizontal* and *Middle vertical* were constructed starting with an increment of 1 mm thickness of composite resin. The fibre was placed on top of the composite and then a second increment of composite was placed to fill the mold, slightly pressed against the fibre using a glass slide, with a polyester film interposed between the glass and the mold. In the case of groups A and B, the fabric was first wetted and then placed on the first layer of composite resin.

The light-curing of the specimens was performed in two phases. Each phase consisted of 60 seconds of light-exposure: 20 seconds for each third of the beam length. The LED curing light unit had 1100 mW/cm^2 power and 430-480 nm wavelength and its tip was positioned at 5 mm distance from the specimen.

After removing the specimens out of the mold, the dimensional parameters were assessed using a digital caliper with 0.01 mm accuracy. The material excess was removed from the edges with a scalpel blade. When necessary, the specimens were finished with a silicon carbide grinding paper, until the dimensions of 2.0 ± 0.1 mm x 2.0 ± 0.1 mm x 25.0 ± 1 mm were obtained without touching the fibre surfaces. Test specimens out of dimensional tolerance which could not be adjusted were rejected and new ones were prepared. All the procedures were performed by the same person in order to calibrate the protocol. The specimens were stored at room temperature for 24 hours before mechanical testing.

b. Mechanical testing

The three-point bend test is a short duration test that allows to determine the internal stress that occurs in the mass as a result of external forces action and of the following factors: test load speed, crosshead speed, sample deformation speed, ultimate bending force that each sample can hold, the ultimate strength, the deformation and the flexural rigidity; the diagram of the force variation in relation with time and deformation is obtained.

Five specimens (n = 5) from each set were subjected to three-point bending test using ISO 4049 flexural test and a universal testing machine WDW-5CE type. The flexural strength and the flexural modulus from the measured deflection of the specimens were assessed.

The specimens have been tested by static short duration loads at a cross-head speed of 0.1mm/min, at room temperature and in normal humidity conditions. The load was applied at the middle of the test specimen perpendicular to the long axis, with a rounded-ended striker and with 20.4 mm between the two supports. Loading was removed when either sample showed catastrophic rupture or a negative slope of load vs. displacement was recorded after the peak load, with the load values dropping continually below 85% of the peak load [282].

The maximum stress at the beam surface is [205]:

$$\sigma_{\max} = \frac{M_{\max} \cdot h/2}{I_z} \tag{1}$$

where: M_{max} - maximum bending moment;

I_z - moment of inertia;

h - height of the test specimen.

In these specific conditions, the maximum bending moment in the beam is located in the middle of the test specimen and is equal to $M_{max} = Fl / 4$; therefore the location of the maximum tensile and compressive flexural stresses is also in the middle of the beam, on the lower surface of the sample for the tension and upper surface of the sample for the compression.

The moment of inertia for a rectangular cross section beam is: $I_z = bh^3 / 12$, where b is the width of the test specimen.

Substitution of M_{max} and I_z into equation (1) gives:

$$\sigma_{\max} = \frac{3}{2} \cdot \frac{F \cdot l}{b \cdot h^2} \tag{2}$$

where: F - maximum load.

The maximum deflection of the beam is [170]:

$$f_{\max} = \frac{F \cdot l^3}{48 \cdot E \cdot I_z} \tag{3}$$

where: l - the distance between the supports.

Substitution of I_z into equation (3) gives the following formulae for the flexural modulus *(E)*:

$$E = \frac{F \cdot l^3}{4 \cdot f_{\max} \cdot bh^3} \tag{4}$$

where: $f_{\max}$ - the maximum deflection of beam.

c. Statistical methods

Mean data values and SDs were calculated for initial and final flexural strength and for initial and final flexural modulus. The initial flexural strength (IFS) corresponds to the first cracks appeared in the sample, which are usually initiated in the tension part of the samples. The final flexural strength (FFS) corresponds to the peak load, which for some samples coincides with the catastrophic failure.

One-way analysis of variance (ANOVA) and Tukey post hoc multiple comparisons test were used to determine the significance of the difference between mean values of calculated flexural strength and modulus of elasticity for each main category. All tests were performed at a significance level of $\alpha = 0.05$.

Results

Under flexural conditions simulated in this experiment, the principal stress on the superior aspect of the beam is compressive, while that on the inferior aspect is tensile. Two failure patterns were noticed: the first one - catastrophic failure, in brittle fashion, at peak load, and the second one – representative for plastic deformation, with an increasing displacement after the peak load, corresponding to a slow decrease in load. The specimens were tested until fracture failure occurred or 4 mm midpoint deflection was attained.

It was noticed that for the samples without reinforcement on the tension side, the first fracture line appeared along the axis of the force, on the inferior part of the composite. The crack evolved up to the junction layer between the fibre and the composite veneer and then the fracture spread along the fibre. For the samples with reinforcement on the tension side, cracks appeared at the compression side - the superior part of the composite. The fracture failure describes two patterns: the complete transversal separation of the specimens in two parts and the delamination of the composite, while maintaining the fibre integrity (Fig. 43 - 48).

The initial flexural strength (IFS) and initial flexural modulus (IFM) values were calculated based on the initial loads, equivalent to the initial fracture force and the initial deflection of the specimens. The final flexural strength (IFS) and the final flexural modulus (IFM) values were calculated based on the maximum loads, equivalent to the peak load and the final deflection of the specimens (max. 4.5 mm). It must be pointed out that for the samples which were fractured in one stage the initial and the final flexural strength were the same (especially for unreinforced samples and for some of glass-fibre reinforced samples).

The ANOVA test was performed in the first step to determine if any significant differences exist between group means. The Tukey test was run to find which group means exhibit a significant difference.

All the reinforcements increased to some extent both initial and final flexural strength. The best results, in both cases, were manifested by C3U (459.59±18.75 MPa - initial and 541.33±47.98 MPa - final).

For the initial flexural strength, significant improved performances were demonstrated also by D3T (135.44±26.82 MPa) and C2V (112.11±13.10 MPa). The lack of statistical significance for the other cross-sectional designs can be correlated with the large variance of the determinations.

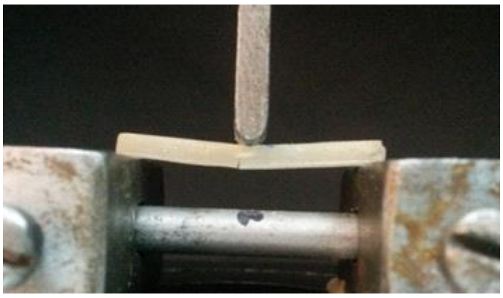


Fig. 43. Construct – compression side

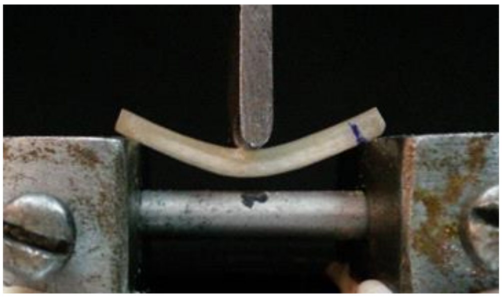


Fig. 44. Construct fibre – U-shape

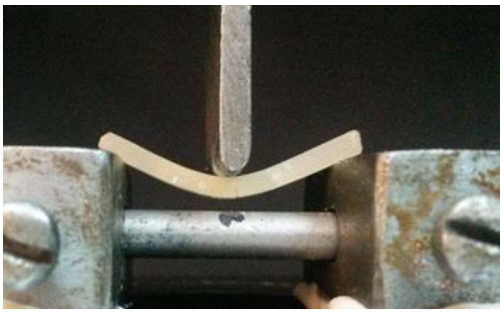


Fig. 45. Construct – middle vertical

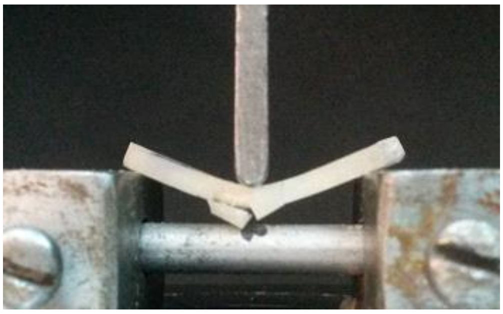


Fig. 46. Construct – middle vertical

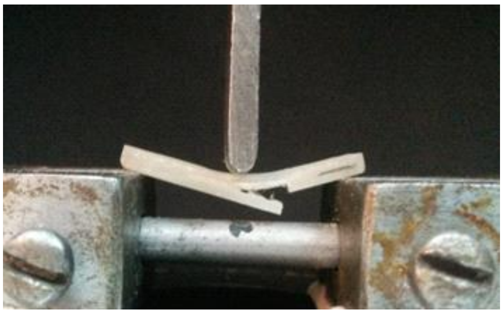


Fig. 47. Dentapreg – middle horizontal

Fig. 48. Dentapreg – tension

The evaluation of the final tensile strength reveals that the braided polyethylene fibres assure a better flexural strength compared with glass-fibres. In the groups of Construct fibres, one can notice that the disposition of the fibres is the main factor that makes the difference, the dimension being the second one (Tables 39 and 40). The best cross-sectional design is *U-shape* followed by the placement of the fibres on the tensile side (*Tension* groups): C3T = 427.41±52.94 MPa and C2T = 377.41±45.42 MPa. Also, C2D (*Double* fibres on tensile side) showed an increased toughness (284.99±5.0 MPa), but significantly lower than C2T.

It is already commonly accepted that the placement of the fibres, disregarding their type, on the tensile side, improves the flexural strength of the samples [165, 173, 207, 283, 284]. In this case, the fracture pattern for polyethylene fibres samples changes to more ductile and elongated compared to the glass-fibres or unreinforced samples for which the fracture is brittle and instantaneous.

From the clinical point of view this ductile fracture behaviour should allow the possibility of prolonging the intraoral life-span of the fibre-reinforced bridges by allowing some repairs to be performed. In this particular situation, the difference between the initial flexural strength and the final flexural strength becomes relevant. This is not the case when the rupture is sudden: no intra-oral interventions are possible and the initial flexural strength becomes the most important factor in clinical surviving of the FRC bridges.

Table 39. One-way analysis of variance - initial flexural strength (MPa)

SUMMARY				
Groups (n=5)	*Sum*	*Average*	*Variance*	*SD*
C3T	208,16	69,39	2094,81	45,77
C3C	149,66	49,89	1298,22	36,03
C3V	97,75	32,58	2,92	1,71
C3H	163,67	54,56	2007,20	44,80
C3U	1378,77	459,59	351,41	18,75
D3T	406,32	135,44	719,35	26,82
D3C	118,70	39,57	259,32	16,10
D3V	185,72	61,91	1011,49	31,80
D3H	69,96	23,32	9,57	3,09
C2T	87,20	29,07	0,18	0,42
C2C	147,70	49,23	1674,53	40,92
C2V	336,34	112,11	171,62	13,10
C2H	86,34	28,78	29,19	5,40
C2D	89,50	29,83	1,59	1,26
D2C	164,39	54,80	2001,86	44,74
D2T	84,47	28,16	0,49	0,70
D2V	84,13	28,04	0,41	0,64
D2H	71,20	23,73	0,40	0,64
D2D	88,51	29,50	0,25	0,50
F	67,37	22,46	0,31	0,56

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	534538,2	19	28133,59	48,35976	1E-21	1,852892
Within Groups	23270,25	40	581,7562			
Total	557808,5	59				

Table 40. One-way analysis of variance - for final flexural strength, at peak value (MPa)

SUMMARY				
Groups (n=5)	*Sum*	*Average*	*Variance*	*SD*
C3T	1282,22	427,41	2803,12	52,94
C3C	266,01	88,67	12,67	3,56
C3V	647,76	215,92	641,63	25,33
C3H	610,17	203,39	3018,93	54,94
C3U	1623,98	541,33	2302,02	47,98
D3T	379,71	156,11	1726,91	41,56
D3C	289,44	96,48	3523,16	59,36
D3V	375,55	125,18	0,81	0,90
D3H	447,94	149,31	1847,04	42,98
C2T	1132,22	377,41	2063,26	45,42
C2C	301,59	100,53	100,90	10,04
C2V	588,03	196,01	1222,34	34,96
C2H	566,25	188,75	472,33	21,73
C2D	854,98	284,99	25,00	5,00
D2C	366,16	122,05	279,79	16,73
D2T	730,66	243,55	429,97	20,74
D2V	546,09	182,03	331,33	18,20
D2H	348,68	116,23	24,09	4,91
D2D	524,00	174,67	16,33	4,04
F	67,37	22,46	0,31	0,56

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	893666,09	19	47035,06	49,159	7E-22	1,8529
Within Groups	38271,64	40	956,791			
Total	931937,73	59				

Table 41. Tukey's multiple comparison test (Tukey's HSD) - pair-wise comparison between means for initial flexural strength. Statistically significant differences are high-lighted.

Groups		C3U	D3T	C2V	C3T	D3V	D2C	C3H	C3C	C2C	D3C	C3V	C2D	D2D	C2T	C2H	D2T	D2V	D3H	D2H	F
	Average	459,59	128,81	112,11	69,39	61,91	54,80	54,56	49,89	49,23	39,57	32,58	29,83	29,50	29,07	28,78	28,16	28,04	26,39	23,73	22,46
C3U	459,59	0,00																			
D3T	128,81	330,78	0,00																		
C2V	112,11	347,48	16,69	0,00																	
C3T	69,39	390,20	59,42	42,73	0,00																
D3V	61,91	397,68	66,90	50,21	7,48	0,00															
D2C	54,80	404,79	74,01	57,32	14,59	7,11	0,00														
C3H	54,56	405,03	74,25	57,56	14,83	7,35	0,24	0,00													
C3C	49,89	409,70	78,92	62,23	19,50	12,02	4,91	4,67	0,00												
C2C	49,23	410,35	79,57	62,88	20,15	12,67	5,56	5,32	0,65	0,00											
D3C	39,57	420,02	89,24	72,55	29,82	22,34	15,23	14,99	10,32	9,67	0,00										
C3V	32,58	427,01	96,22	79,53	36,80	29,32	22,21	21,98	17,30	16,65	6,98	0,00									
C2D	29,83	429,76	98,97	82,28	39,55	32,07	24,96	24,73	20,05	19,40	9,73	2,75	0,00								
D2D	29,50	430,08	99,30	82,61	39,88	32,40	25,29	25,05	20,38	19,73	10,06	3,08	0,33	0,00							
C2T	29,07	430,52	99,74	83,05	40,32	32,84	25,73	25,49	20,82	20,17	10,50	3,51	0,76	0,44	0,00						
C2H	28,78	430,81	100,03	83,33	40,61	33,13	26,02	25,78	21,10	20,45	10,79	3,80	1,05	0,72	0,29	0,00					
D2T	28,16	431,43	100,65	83,96	41,23	33,75	26,64	26,40	21,73	21,08	11,41	4,43	1,68	1,35	0,91	0,62	0,00				
D2V	28,04	431,55	100,77	84,07	41,34	33,86	26,75	26,52	21,84	21,19	11,52	4,54	1,79	1,46	1,03	0,74	0,11	0,00			
D3H	26,39	433,20	102,42	85,72	42,99	35,51	28,40	28,17	23,49	22,84	13,17	6,19	3,44	3,11	2,68	2,39	1,76	1,65	0,00		
D2H	23,73	435,85	105,07	88,38	45,65	38,17	31,06	30,82	26,15	25,50	15,83	8,85	6,10	5,77	5,33	5,05	4,42	4,31	2,66	0,00	
F	22,46	437,13	106,35	89,66	46,93	39,45	32,34	32,10	27,43	26,78	17,11	10,13	7,38	7,05	6,61	6,32	5,70	5,59	3,94	1,28	0,00

The placement of the C fibres on the compression side, either 2 or 3 mm, improved the flexural strength but not in a statistically significant manner. This is the case for all the fibres placed in the compression side of the samples. For these situations, the mechanical performances of the samples are dictated mainly by the mechanical properties of the veneering composite [165, 283, 284]. The same goes for the middle horizontal disposition of the fibres where there are no remarkable improvements and, supplementary, the thickness of the veneering composite at the inferior part of the sample plays an important role. In these situations, after the failure of the inferior layer of the composite, the tensile stress is transferred completely to the fibre.

Table 42. Tukey's multiple comparison test (Tukey's HSD) - pair-wise comparison between means for final flexural strength. Statistically significant differences are high-lighted.

Groups		C3U	C3T	C2T	C2D	D2T	C3V	C3H	C2V	D2V	D2D	D3H	D3T	D3V	D2C	D2H	C2H	C2C	D3C	C3C	F
	Average	541,33	427,41	377,41	258,83	243,55	215,92	203,39	196,01	182,03	165,33	149,31	126,57	125,18	122,05	116,23	104,69	100,53	96,48	88,67	22,46
C3U	541,33	0,00																			
C3T	427,41	113,92	0,00																		
C2T	377,41	163,92	50,00	0,00																	
C2D	258,83	282,50	168,58	118,58	0,00																
D2T	243,55	297,77	183,85	133,85	15,27	0,00															
C3V	215,92	325,40	211,49	161,49	42,91	27,63	0,00														
C3H	203,39	337,93	224,01	174,02	55,44	40,16	12,53	0,00													
C2V	196,01	345,31	231,39	181,40	62,82	47,54	19,91	7,38	0,00												
D2V	182,03	359,29	245,37	195,38	76,80	61,52	33,89	21,36	13,98	0,00											
D2D	165,33	375,99	262,07	212,07	93,49	78,22	50,59	38,06	30,68	16,70	0,00										
D3H	149,31	392,01	278,09	228,10	109,51	94,24	66,61	54,08	46,70	32,72	16,02	0,00									
D3T	126,57	414,75	300,84	250,84	132,26	116,98	89,35	76,82	69,44	55,46	38,76	22,74	0,00								
D3V	125,18	416,14	302,22	252,22	133,64	118,37	90,74	78,21	70,83	56,85	40,15	24,13	1,39	0,00							
D2C	122,05	419,27	305,35	255,36	136,77	121,50	93,87	81,34	73,96	59,98	43,28	27,26	4,52	3,13	0,00						
D2H	116,23	425,10	311,18	261,18	142,60	127,33	99,69	87,17	79,79	65,81	49,11	33,09	10,34	8,96	5,83	0,00					
C2H	104,69	436,63	322,71	272,71	154,13	138,86	111,23	98,70	91,32	77,34	60,64	44,62	21,88	20,49	17,36	11,53	0,00				
C2C	100,53	440,79	326,88	276,88	158,30	143,02	115,39	102,86	95,48	81,50	64,80	48,78	26,04	24,65	21,52	15,70	4,16	0,00			
D3C	96,48	444,85	330,93	280,93	162,35	147,08	119,44	106,91	99,53	85,55	68,85	52,83	30,09	28,70	25,57	19,75	8,22	4,05	0,00		
C3C	88,67	452,65	338,74	288,74	170,16	154,88	127,25	114,72	107,34	93,36	76,66	60,64	37,90	36,51	33,38	27,56	16,02	11,86	7,81	0,00	
F	22,46	518,87	404,95	354,95	236,37	221,10	193,46	180,93	173,55	159,58	142,88	126,86	104,11	102,73	99,60	93,77	82,24	78,07	74,02	66,21	0,00

Table 43. One-way analysis of variance - initial flexural modulus (GPa)

SUMMARY				
Groups (n=5)	*Sum*	*Average*	*Variance*	*SD*
C3T	14,81	4,94	1,207	1,10
C3C	34,16	11,39	100,873	10,04
C3V	37,90	12,63	199,477	14,12
C3H	13,25	4,42	0,048	0,22
C3U	14,74	4,91	0,308	0,55
D3T	12,10	4,03	0,353	0,59
D3C	18,05	6,02	27,218	5,22
D3V	40,38	13,46	45,841	6,77
D3H	9,81	3,27	0,015	0,12
C2T	16,44	5,48	8,635	2,94
C2C	28,78	9,59	120,730	10,99
C2V	12,28	4,09	0,226	0,47
C2H	40,41	13,47	23,838	4,88
C2D	28,80	9,60	0,281	0,53
D2C	47,88	15,96	58,047	7,62
D2T	39,40	13,13	1,796	1,34
D2V	31,47	10,49	0,626	0,79
D2H	27,71	9,24	7,632	2,76
D2D	124,50	41,50	6,750	2,60
F	14,14	4,71	3,172	1,78

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4002,18	19	210,6411	6,939575	1,47E-07	1,852892
Within Groups	1214,144	40	30,3536			
Total	5216,324	59				

Table 44. One-way analysis of variance - final flexural modulus (GPa), at the peak value

SUMMARY				
Groups (n=5)	*Sum*	*Average*	*Variance*	*SD*
C3T	17,05	5,68	0,20	0,44
C3C	9,49	3,16	0,07	0,26
C3V	5,94	1,98	0,13	0,36
C3H	5,26	1,75	0,04	0,19
C3U	14,02	4,67	0,28	0,53
D3T	7,33	2,68	1,05	1,03
D3C	5,67	1,88	0,58	0,76
D3V	10,18	3,39	1,12	1,06
D3H	8,52	2,42	0,01	0,10
C2T	13,19	4,40	0,12	0,34
C2C	8,48	2,83	0,07	0,27
C2V	5,34	1,78	0,14	0,37
C2H	4,38	1,46	0,06	0,25
C2D	15,09	5,03	0,01	0,09
D2C	18,55	6,18	0,83	0,91
D2T	18,52	6,17	0,02	0,15
D2V	9,49	4,37	0,02	0,15
D2H	15,11	2,54	0,23	0,48
D2D	15,29	5,10	0,25	0,50
F	8,04	2,68	1,20	1,10

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	138,1911	19	7,273216	17,98772	5,87E-14	1,852892
Within Groups	16,17374	40	0,404343			
Total	154,3648	59				

Another aspect that is worth mentioning, even if not statistically significant, is the position of the fibre in the middle of the sample. The vertical orientation (*Vertical* groups), parallel to the force direction, seems to work better in terms of flexural strength than horizontal

(*Horizontal* groups). This seems to be in contradiction with the findings of other studies [284-286].

On the initial flexural modulus, no statistically significant correlations of E were found for the cross-sectional designs tested in this study, except for D2D which proved highly rigid (41.4±2.6 MPa) (Table 41 - 46). Overall, for both the initial and final flexural modulus, the glass-fibres seem to increase the flexural modulus. Also, placing the fibres on the pressure side (*Compression* groups) increases the flexural modulus, while placing the fibres on the tension side (*Tension* groups) increases the flexural strength. This agrees with the findings of other research studies [283, 284]. A meta-regression study pointed out a lower flexural modulus of polyethylene reinforced specimens, regardless the dimension, impregnation, manufacturer or type of composite [173].

Table 45. Tukey's multiple comparison test (Tukey's HSD) - pair-ways comparison between means for initial flexural modulus. Statistically significant differences are high-lighted.

Groups		D2D	D2C	C2H	D3V	D2T	C3V	C3C	D2V	C2D	C2C	D2H	D3C	C2T	C3T	C3U	F	C3H	C2V	D3T	D3H
	Average	41,50	15,96	13,47	13,46	13,13	12,63	11,39	10,49	9,60	9,59	9,24	6,02	5,48	4,94	4,91	4,71	4,42	4,09	4,03	3,27
D2D	41,50	0,00																			
D2C	15,96	25,54	0,00																		
C2H	13,47	28,03	2,49	0,00																	
D3V	13,46	28,04	2,50	0,01	0,00																
D2T	13,13	28,37	2,82	0,33	0,33	0,00															
C3V	12,63	28,87	3,33	0,84	0,83	0,50	0,00														
C3C	11,39	30,11	4,57	2,08	2,07	1,75	1,25	0,00													
D2V	10,49	31,01	5,47	2,98	2,97	2,64	2,14	0,90	0,00												
C2D	9,60	31,90	6,36	3,87	3,86	3,53	3,03	1,78	0,89	0,00											
C2C	9,59	31,91	6,37	3,88	3,87	3,54	3,04	1,79	0,90	0,01	0,00										
D2H	9,24	32,26	6,72	4,23	4,22	3,90	3,40	2,15	1,25	0,36	0,36	0,00									
D3C	6,02	35,48	9,94	7,45	7,44	7,12	6,62	5,37	4,47	3,59	3,58	3,22	0,00								
C2T	5,48	36,02	10,48	7,99	7,98	7,65	7,15	5,91	5,01	4,12	4,11	3,76	0,54	0,00							
C3T	4,94	36,56	11,02	8,53	8,52	8,20	7,69	6,45	5,55	4,66	4,65	4,30	1,08	0,54	0,00						
C3U	4,91	36,59	11,05	8,56	8,55	8,22	7,72	6,47	5,58	4,69	4,68	4,32	1,10	0,57	0,03	0,00					
F	4,71	36,79	11,25	8,76	8,75	8,42	7,92	6,67	5,78	4,89	4,88	4,52	1,30	0,77	0,23	0,20	0,00				
C3H	4,42	37,08	11,54	9,05	9,05	8,72	8,22	6,97	6,07	5,19	5,18	4,82	1,60	1,06	0,52	0,50	0,30	0,00			
C2V	4,09	37,41	11,87	9,38	9,37	9,04	8,54	7,29	6,40	5,51	5,50	5,14	1,92	1,39	0,84	0,82	0,62	0,32	0,00		
D3T	4,03	37,47	11,93	9,44	9,43	9,10	8,60	7,35	6,46	5,57	5,56	5,20	1,98	1,45	0,90	0,88	0,68	0,38	0,06	0,00	
D3H	3,27	38,23	12,69	10,20	10,19	9,86	9,36	8,12	7,22	6,33	6,32	5,97	2,75	2,21	1,67	1,64	1,44	1,15	0,82	0,76	0,00

Table 46. Tukey's multiple comparison test (Tukey's HSD) - pair-ways comparison between means for final flexural modulus. Statistically significant differences are high-lighted.

Groups		D2C	D2T	C3T	D2D	C2D	C3U	C2T	D2V	D3V	C3C	C2C	F	D3T	D2H	D3H	C3V	D3C	C2V	C3H	C2H
	Average	6,18	6,17	5,68	5,10	5,03	4,67	4,40	4,37	3,39	3,16	2,83	2,68	2,68	2,54	2,42	1,98	1,88	1,78	1,75	1,46
D2C	6,18																				
D2T	6,17	0,01																			
C3T	5,68	0,50	0,49																		
D2D	5,10	1,09	1,08	0,59																	
C2D	5,03	1,15	1,14	0,65	0,06																
C3U	4,67	1,51	1,50	1,01	0,42	0,36															
C2T	4,40	1,79	1,78	1,29	0,70	0,63	0,28														
D2V	4,37	1,81	1,80	1,31	0,72	0,66	0,30	0,02													
D3V	3,39	2,79	2,78	2,29	1,70	1,64	1,28	1,00	0,98												
C3C	3,16	3,02	3,01	2,52	1,93	1,87	1,51	1,23	1,21	0,23											
C2C	2,83	3,35	3,34	2,86	2,27	2,20	1,85	1,57	1,55	0,57	0,34										
F	2,68	3,50	3,49	3,00	2,41	2,35	1,99	1,72	1,69	0,71	0,48	0,15									
D3T	2,68	3,51	3,50	3,01	2,42	2,36	2,00	1,72	1,70	0,72	0,49	0,15	0,01								
D2H	2,54	3,64	3,63	3,14	2,55	2,49	2,13	1,85	1,83	0,85	0,62	0,28	0,14	0,13							
D3H	2,42	3,76	3,75	3,26	2,68	2,61	2,25	1,98	1,95	0,97	0,74	0,41	0,26	0,26	0,13						
C3V	1,98	4,20	4,19	3,70	3,12	3,05	2,69	2,42	2,39	1,41	1,18	0,85	0,70	0,70	0,57	0,44					
D3C	1,88	4,31	4,30	3,81	3,22	3,15	2,80	2,52	2,50	1,52	1,29	0,95	0,80	0,80	0,67	0,54	0,10				
C2V	1,78	4,40	4,39	3,91	3,32	3,25	2,89	2,62	2,59	1,62	1,39	1,05	0,90	0,90	0,77	0,64	0,20	0,10			
C3H	1,75	4,43	4,42	3,93	3,34	3,28	2,92	2,64	2,62	1,64	1,41	1,08	0,93	0,92	0,79	0,67	0,23	0,12	0,03		

Discussions

The rich scientific literature about FRC is motivated by the researchers' belief that these restorations have a great potential. It is unanimously accepted that there is a lack of knowledge in this field due to its novelty and the existing research is either insufficient or inconclusive. A simple transfer of the research methodology from the field of physics, chemistry, plastics or ceramics to composites does not seem to offer the expected answers for an improved application of these composites in the oral cavity.

Unfortunately, the scientific literature does not contain studies that demonstrate clearly enough the relation between the biomechanical performance of the materials and their clinical utilization. Moreover, given the particularity of these materials i.e., their anisotropy and the fact that their biomechanical properties vary in accordance with the fibre/resin ratio, to the fibre's position, orientation and type and to the composite type, the variability of these materials is very high. This opens the way for an extraordinary potential leading to new research and promising results.

Some other factors that make these materials difficult to manage and that have an influence on the biomechanical properties are: fibre surface treatment, impregnation of fibres with resin, water absorption of the matrix and the adhesion between fibre and matrix. For example, the composite matrix allows diffusion and absorption of water, resulting in a decrease of strength and stiffness. The greatest reduction in strength is reported to be in the first 4 weeks of water storage [211].

Various studies have shown that framework design, flexural and fatigue properties, and load-bearing capacities of FRCs have improved [181, 209, 283]. In most studies of dental FRCs, an ISO standard-size bar of the composite material (2mm x 2mm x 25mm) is tested to failure by three-point or four-point load. Such studies usually find that the material's strength is significantly improved by the addition of the reinforcement fibres, but the conclusion usually is that the strength of the resulting structure is still not perfectly suitable for dental restoration. "Such a conclusion does not correlate well with the excellent clinical success achieved by numerous practitioners. Fibre-reinforced dental composite may not work on paper but works extremely well in the mouth." [269]. On the other hand, other authors state that the selection and use of continuous reinforcement is largely on an ad hoc basis. There are diverse claims made by manufacturers, a lack of a thorough understanding of the materials based, and also not a deep understanding of the material required performances for specific applications [282]. The potential of these metal replacing restorations, with all disadvantages that they carry, allow minimal preparation with exceptional aesthetic results at very affordable costs, in a short time. This is very motivating and appealing to many specialists and patients. Nevertheless, the high variability of materials and techniques combined with the execution sensitivity and overall, the reported survival rate can be discouraging for many practitioners.

It is known with certitude that the failure behaviour, stiffness and toughness of FRC bridges are dependent on the components of the composite system and their spatial relation. Considering these aspects, it is a matter of time until the optimum design will be accurately described to ensure the success of this type of restorations.

Conclusions

The cross-sectional design plays an important role in biomechanical performances of FRC restorations. Within the limitations of the present study, it was found that the toughness of the studied FRC systems increased in the case of tensile side placement of the fibres. The U-shape placement of biaxial braided polyethylene fibres on the tensile side of the samples presented the best flexural strength.

2.2.2.3. Load-bearing capacity of direct inlay-retained FRC fixed partial dentures with different cross-sectional pontic design

Aim of the study

The aim of the study was to evaluate the load-bearing capacity of a new cross-sectional design for the pontic of fibre-reinforced composite bridges [282].

Materials and method

a. Specimen preparation

40 extracted intact teeth (20 premolars and 20 molars) were cleaned by curettage, disinfected and then stored in saline solution at room temperature. Each of the 20 samples of FRC bridges was made on two teeth – premolar and molar - embedded in type IV dental stone (Picodent Z 260 v, Picodent GmBH, Germany), replicating the situation of one missing first molar with 10 mm mesio-distal length.

The bridges were retained by inlays in the class II cavities prepared on the distal and occlusal face of the premolar and on mesial and occlusal face of the molar. For the proximal cavity, the depth in cervical aria was 1.5 mm, the length in buccal-oral direction was 3±0.5 mm and height, in cervico-occlusal direction, was 3±0.5 mm between the cervical and occlusal embrasures. For the occlusal cavity, the depth was 1.5 mm, the length in buccal-oral direction was 3 mm and in mesio-distal direction it was 5 mm. The distance between the abutment teeth was 10 mm.

Consequently, the bridges had the following dimensional parameters (Fig. 49):

- 2 class II inlays:
  - *thickness of 1.5 mm occlusal and 1,5 mm cervical*
  - *mezio-distal length = 5±0.5 mm*
  - *buccal-oral width of the connector and vertical cavity = 3±0.5 mm*
  - *cervico-occlusal height of connector = 3±0.5 mm*
- 1 pontic:
  - *length = 10±0.5 mm*
  - *height = 7±0.5 mm*
  - *width = 8±0.5 mm*

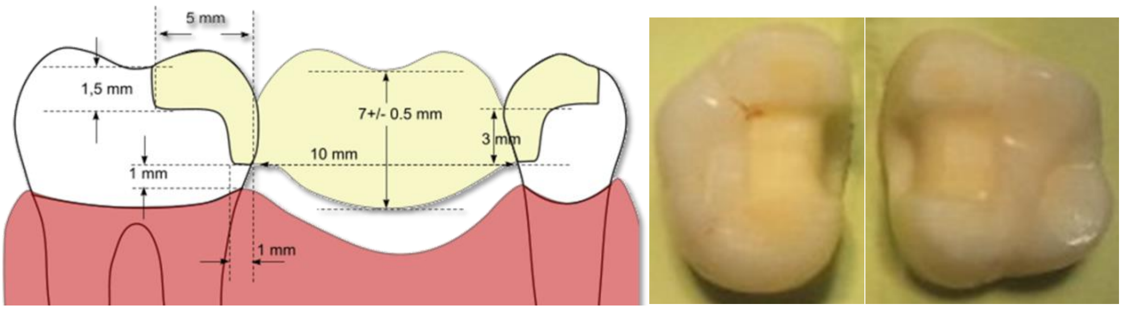


Fig. 49. Dimensional parameters of the bridges

The FDPs were manufactured using two silicon molds (Registrado Clear, VOCO, Germany) in order to achieve the standard dimensions and the same aspect for the mucosal and occlusal sides. The occlusal side replicated the occlusal face of a first maxillary molar.

The inlay-retained FRC FDPs were made by using 3 mm braided polyethylene ribbon fibres (Construct, Kerr, USA), 2 types of composites (*Filtek Bulk Fill Posterior Restorative* 3M/ESPE, St. Paul, MN, USA and *Filtek Z250*, 3M/ESPE, St. Paul, MN, USA) and two types of adhesives (*Single Bond Universal Adhesive*, 3M ESPE, Germany and *Optibond All –In-One*, Kerr Italia, Italy).

Details of the materials used in this experimental study are given in Table 47 and 48.

Two different cross-sectional designs of the pontic - parallel and adjacent - were used. In making the FPDs the Construct manufacturer's instructions were followed, as well the results of a previous study concerning cross-sectional design of FRC systems [257]. In the respective study the best mechanical behaviour was recorded for a "U"-shaped disposition of the fibres, placed on the tension and lateral sides of the ISO 4049 (2 x 2 x 2.5 mm^3) bar samples.

Table 47. The composite resins used for the bridges and their composition

Brand	Manufacturer	Type	Matrix composition	Inorganic filler content	Lot No.
Filtek Bulk Fill Posterior Restorative	3M/ESPE, St. Paul, MN, USA	Bulk-fill	AUDMA, AFM DDDMA, UDMA	• 100 nm Ytterbium trifluoride (YbF_3) • non-agglomerated/non-aggregated 20nm silica filler and 4 to 11nm zirconia filler • aggregated zirconia/silica cluster filler (20nm silica and 4 to 11 m zirconia particles) • total inorganic filler loading 76.5% by weight (58.4% by volume)	N706090
Filtek Z250	3M/ESPE, St. Paul, MN, USA	Microhybrid	Bis-GMA, bis-EMA, UDMA	• Zirconia 78 wt%, 60 vol%, with a particle size range of 0.01 to 3.5µ (average 0.6µ)	N805733
Filtek Bulk Fill Flow	3M/ESPE, St. Paul, MN, USA	Flowable	BisGMA, BisEMA(6), UDMA and Procrylat	• Zirconia/silica with a particle size range of 0.01 to 3.5µ (average 0.6µ) • Ytterbium trifluoride particle size range of 0.1 to 5µ • Filler loading is 64.5% by weight (42.5% by volume)	N779563

AFM, addition-fragmentation monomers; AUDMA, aromatic dimethacrylate; Bis-GMA, bisphenol-A-glycidyl dimethacrylate; bis-EMA, ethoxylated bisphenol-A-dimethacrylate; DDDMA, 1, 12-Dodecanediol dimethacrylate; UDMA, urethane dimethacrylate; wt%, weight percentage; vol%, volume percentage.

Table 48. Materials used for the bridge samples

Brand	Manufacturer	Type	Characteristics	Lot No.
Construct	Kerr Corporation, Orange, CA, USA	Braided fibre reinforcement ribbon - 3mm	Braided polyethylene fibres with ultra-high strength, silanated, cold plasma treated	5137532
Construct Resin	Dental Lab Products Kerr Corporation, Orange, USA	Wetting resin	Uncured methacrylate ester monomers, photo initiators, inorganic fillers and stabilizing additives	5137527
Single Bond Universal Adhesive	3M ESPE, 3M Deutschland GmbH, Germany	Bonding agent	Self-etch dental adhesive	623865
Optibond All –In-One	Kerr Italia, Salerno, Italy	Bonding agent	Single component, self-etch dental adhesive	5457301
Registrado Clear	VOCO, Germany	Bite registration material	Transparent addition-curing silicone for bite registration, fast setting	1640090
Picodent Z 260 v	Picodent GmBH, Germany	Dental stone, type IV, extrahard	Calcium sulphate x 0.5 H_2O 95-100%	07-2017

According to the disposition of the fibres and the composite material used, 4 groups of FRC FPDs were made with 5 samples for each group (n = 5) (Table 49). In the first group the bridges were made of Filtek Z250 with the two Construct fibres disposed straight and parallel, following the manufacturer indications. In the second group, the composite was also Filtek Z250, but the fibres were disposed respecting the "curved" method described by Waki et al. (2006) [287] and adjacent, supporting the tension side and extending on the buccal and oral sides of the pontic (Fig. 50). In the third group the Filteck Bulk Fill was used and the fibres were straight and parallel. In the fourth group the Filteck Bulk Fill was used with the adjacent and curved disposition of the fibres. The two different adhesives (*Optibond All –In-One* and *Single Bond Universal Adhesive)* were randomly used for each sample.

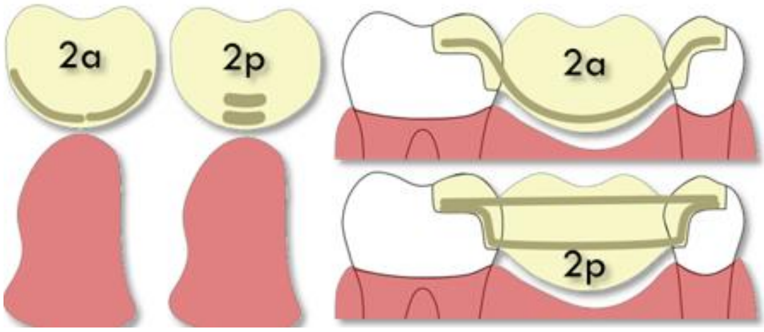


Fig. 50. Architecture of the fibres

Table 49. The four groups' characteristics

Fibres	Composites	No. of fibres	Design	Groups	No. of samples
Construct (C)	***Filteck Z250 (Fz)***	2	parallel (p)	CFz2p	5
		2	adjacent (a)	CFz2a	5
	Filteck Bulk Fill (Fb)	2	parallel (p)	CFb2p	5
		2	adjacent (a)	CFb2a	5

In the first step of manufacturing of the bridges, the cervical mold for the mucosal side of the pontic was positioned between the teeth. Then the prepared cavities were sealed with the adhesive. Considering the same surface contact between the bridge and the teeth, for each of the two abutments a different adhesive was used. The light curing time was 20 s for each preparation. The photo-polymerization was done with a VALO Cordless LED curing light unit (Ultradent Products, USA), with 1100 mW/cm^2 power and 395-480 nm wavelength and its tip was positioned at 5 mm distance from the specimen. Approximately 0.2 mm of composite resin was applied on each box.

For the groups with the adjacent disposition of the fibres, an approximately 1.5 mm of composite resin was applied on the cervical mold, as the base of the pontic to the maximum buccal-oral diameter. Two Construct braid fibres were impregnated with Construct Resin (Dental Lab Products, Kerr Corporation, USA) and placed in the bed of the composite, in a curved manner and one besides the other, covering the mucosal side of the pontic and closely adapted to the prepared boxes. Each surface was light-cured for 40 seconds.

For the groups with the parallel disposition of the fibres, the first layer of the composite was placed up to the level of cervical limit of the proximal boxes. One Construct braid was placed straight between the abutments, closely fitted to the abutments cavities. The strap was light cured for 40 seconds for each segment. The second strap was placed on another layer of composite in order to be placed at the level of the horizontal boxes. The second strap was light cured for 40 seconds for each segment.

For both groups the bridges were completed with the composite resin to restore the occlusal surfaces of the abutments and light-cured for 60 seconds. The occlusal surface of the pontic was completed using the transparent silicon mold replicating the morphology of a first maxillary molar. The surface was light cured for 60 seconds. After removing the two molds, the bridges were light cured for 60 seconds for each surface. The dimensions of the bridges were checked, finished and polished using Kerr Composite Finishing System.

The samples were stored in distilled water for 24 hours before testing.

b. Mechanical testing

The specimens were subjected to three-point bending test using a universal testing machine WDW-5CE type with a maximum load of 25kN. The specimens have been tested by static short duration loads at a cross-head speed of 0.1mm/min, at room temperature and in normal humidity conditions. The load was applied at the middle of the test specimen perpendicular to the long axis, with a rounded-ended striker of 6 mm diameter. Loading was removed when either sample showed catastrophic rupture or a negative slope of load vs. displacement was recorded after the peak load, with the load values dropping continually below 85% of the peak load [282].

The diagram of the force variation in relation with time and deformation was obtained; the initial fracture force, maximum force, stress at the connector levels and initial and final deformation were assessed.

The stress at the connectors level was [205]:

$$\boldsymbol{\sigma = \frac{M}{W_z}}$$

σ = stress in the specimen

M = bending moment

W_z = modulus axial

The specimen was considered as a double embedded beam.

The indeterminacy of the beam was lifted up and the value of the bending moment in the junction was assessed as:

$$\boldsymbol{M = \frac{F\ x\ l}{8}}$$

F = initial / maximum fracture load

l = length of the pontic (distance between the junctions)

$$\boldsymbol{W_z = \frac{b\ x\ h^2}{6}}$$

b = width of the pontic

h = height of the pontic

c. Statistical method

Mean data values and SDs were calculated for initial and final load fracture, initial and final deformation of the pontic and initial and final fracture stress in the junctions. The initial flexural load corresponds to the first cracks appeared in the sample, which are usually initiated in the junctions' part of the bridges. The final flexural load corresponds to the peak load, which for some samples coincides with the catastrophic failure.

Two-way analysis of variance (ANOVA) and Tukey post hoc multiple comparisons test were used to determine the significance of the difference between mean values of recorded flexural load, deformations and initial and final fractures stress in the junctions for each main category. The independent factors were the composite material and the cross-sectional pontic design. The dependent factors were initial and final fracture load, initial and maximal deformations and initial and maximal stress in the junctions. All tests were performed at a significance level of $\alpha = 0.05$.

Results

All the samples demonstrated a perfect elastic behaviour, as the diagrams showed.

Failure analyses revealed that the initiation of the fracture was at the level of the connectors, between the pontic and the retainers, these zones proving to be the weakest points of the bridges. Two different failure patterns were noticed: (1) from the cervical aspect of the connectors, the fracture is propagated oblique, in the mass of the composite, to the middle of the occlusal face, through the buccal and oral faces, with or without delamination of the composite from these faces – groups CFz2p and CFb2p; (2) from the connectors, the fracture is propagated to the occlusal face, preserving the buccal and oral faces; new fractures appeared, in the compression area, around the loading point, interesting the cusps, above the highest position of the fibres (Fig. 51 and Fig. 52).

For all the samples the moment of total destruction of the bridges was delayed related to the moment of initial fracture, supporting the importance of the fibres in sustaining the mechanics of the restoration. This allows the intraoral maintenance of the bridge even after the fissure appearance, which from esthetical and psychological point of view is very important.

Fig. 51. Fracture pattern for parallel design of the fibres

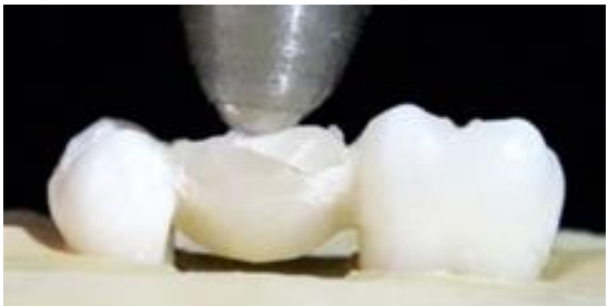


Fig. 52. Fracture pattern for adjacent design of the fibres

None of the samples showed any debonding of the dental bridges from the abutments.

Significant differences ($p < 0.05$) for initial fracture forces values were found between the groups with adjacent disposition (CFb2a = 1565.2 ± 126.5 N; CFz2a = 1380.8 ± 29 N) and parallel disposition of the fibres (CFb2p = 1087.7 ± 133.3 N; CFz2p = 1212.8 ± 126.8 N) (Table 50). For the same cross-sectional design, there are no significant differences for the type of the composite that was used. But two-way ANOVA test showed that the combinations between the fibres disposition and the composites are relevant, and the best results are in the case of CFb2a (Table 51 and Table 52).

The maximum fracture recorded loads were due to the architecture of the fibres and not to the composite type (Table 53). The maximum mean values were recorded for CFz2a group (1633.5 ± 44.8 N) (Table 50), but the combination between the design of the pontic and the composite type was not statistical relevant (Table 53).

Table 50. Mean values recorded for initial fracture load and maximum load (N)

	Initial fracture load				Maximum load			
	CFb2p	CFb2a	CFz2p	CFz2a	CFb2p	CFb2a	CFz2p	CFz2a
Average	1.087,7	1.565,2	1.212,8	1.380,8	1.291,4	1.574,7	1.504,7	1.633,5
Std. Dev.	133,3	126,5	126,8	29,0	17,7	141,5	47,3	44,8
Err.max	116,8	110,8	111,2	25,4	15,5	124,0	41,5	39,3
Max	1.204,5	1.676,0	1.324,0	1.406,2	1.307,0	1.698,8	1.546,2	1.672,8
Min	970,9	1.454,4	1.101,7	1.355,4	1.275,9	1.450,7	1.463,3	1.594,3

Table 51. Two-way analysis of variance initial fracture load (KN)

SUMMARY	2p	2a	Total			
Fb						
Count	5	5	10			
Sum	5,4385	7,826	13,2645			
Average	1,0877	1,5652	1,32645			
Variance	0,017756	0,015992	0,078334			
Fz						
Count	5	5	10			
Sum	6,0642	6,9039	12,9681			
Average	1,21284	1,38078	1,29681			
Variance	0,016081	0,00084	0,015355			
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0,004393	1	0,004393	0,346774	0,564167	4,493998
Columns	0,520741	1	0,520741	41,10952	8,61E-06	4,493998
Interaction	0,119784	1	0,119784	9,456281	0,007248	4,493998
Within	0,202675	16	0,012667			
Total	0,847592	19				

Table 52. TUKEY'S multiple comparison test (TUKEY'S HSD) - pair-ways comparison between means for initial fracture load. statistically significant differences are high-lighted (p<0,05)

Groups		CFb2p	CFb2a	CFz2p	CFz2a
	Average	1,0877	1,5652	1,21284	1,38078
CFb2p	1,0877				
CFb2a	1,5652	0,4775			
CFz2p	1,21284	0,12514	0,35236		
CFz2a	1,38078	0,29308	0,18442	0,16794	

Table 53. Two-way analysis of variance maximum load (KN)

SUMMARY	2p	2a	Total			
Fb						
Count	5	5	10			
Sum	6,4572	7,8737	14,3309			
Average	1,29144	1,57474	1,43309			
Variance	0,000314	0,020026	0,031334			
Fz						
Count	5	5	10			
Sum	6,5062	8,1676	14,6738			
Average	1,30124	1,63352	1,46738			
Variance	0,012204	0,002007	0,036985			
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0,005879	1	0,005879	0,680616	0,421505	4,493998
Columns	0,473673	1	0,473673	54,8373	1,49E-06	4,493998
Interaction	0,002999	1	0,002999	0,347172	0,563946	4,493998
Within	0,138205	16	0,008638			
Total	0,620756	19				

Table 54. Mean values for initial junctional stress and final junctional stress (N/mm^2)

	σinitial				σfinal			
	CFb2p	CFb2a	CFz2p	CFz2a	CFb2p	CFb2a	CFz2p	CFz2a
Average	289,5	420,6	327,8	359,8	343,7	423,1	351,7	426,0
Std. Dev.	36,3	33,5	37,9	21,7	7,8	37,6	35,6	33,2
Err.max	31,8	29,4	33,3	19,0	6,8	33,0	31,2	29,1
Max	321,3	450,0	361,0	378,8	350,5	456,1	382,9	455,1
Min	257,7	391,2	294,5	340,7	336,8	390,2	320,5	396,9

The maximum stress appeared at the initial fracture force at the level of the connector was recorded in the case of CFb2a group (420.6 ± 33.5 N) (Table 54). Both, the fibres disposition and the type of composite are relevant for this situation (Table 55, Table 56). The final stress in the connectors is maximum for the groups with the adjacent fibres disposition, independent of the composite type (Table 57).

The maximum initial deformation, recorded at the moment of the fracture initiation, appeared for the adjacent fibres groups (CFb2a = 0.4845 ± 0.0322 mm, CFz2a = 0.4985 ± 0.0461 mm) (Table 59, 61). If in this case, there is no significant difference between these two groups (Table 60), in the case of the final deformation, the difference is significant (CFb2a = 0.6076 ± 0.0171 mm, CFz2a = 0.8816 ± 0.0583 mm) (Table 62).

Table 55. Two-way analysis of variance initial stress in the connector (KN)

SUMMARY	2p	2a	Total
Fb			
Count	5	5	10
Sum	1,447266	2,102887	3,550153
Average	0,289453	0,420577	0,355015
Variance	0,001316	0,001124	0,005861
Fz			
Count	5	5	10
Sum	1,638768	1,798751	3,437519
Average	0,327754	0,35975	0,343752
Variance	0,001439	0,000471	0,001134

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0,000634	1	0,000634	0,583185	0,456181	4,493998
Columns	0,03326	1	0,03326	30,5792	4,57E-05	4,493998
Interaction	0,012283	1	0,012283	11,29264	0,003979	4,493998
Within	0,017403	16	0,001088			
Total	0,063581	19				

Table 56. TUKEY'S multiple comparison test (TUKEY'S HSD) - pair-ways comparison between means for normal stress in the connector for the initial fracture force. statistically significant differences are high-lighted (p<0,05)

Groups		CFb2p	CFb2a	CFz2p	CFz2a
	Average	0,2895	0,4206	0,3278	0,3598
CFb2p	0,2895				
CFb2a	0,4206	0,131124			
CFz2p	0,3278	0,0383	0,092824		
CFz2a	0,3598	0,070297	0,060827	0,031997	

Table 57. Two-way analysis of variance final stress in the connector (mm)

SUMMARY	2p	2a	Total
Fb			
Count	5	5	10
Sum	1,718356	2,1157	3,834056
Average	0,343671	0,42314	0,383406
Variance	6,06E-05	0,001414	0,00241
Fz			
Count	5	5	10
Sum	1,758602	2,130069	3,888671
Average	0,35172	0,426014	0,388867
Variance	0,001268	0,001104	0,002587

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0,000149	1	0,000149	0,155095	0,698912	4,493998
Columns	0,029554	1	0,029554	30,73346	4,45E-05	4,493998
Interaction	3,35E-05	1	3,35E-05	0,034815	0,854329	4,493998
Within	0,015386	16	0,000962			
Total	0,045122	19				

Table 58. Mean values recorded for initial deformation and final deformation (mm)

	Initial deformation				Final deformation			
	CFb2p	CFb2a	CFz2p	CFz2a	CFb2p	CFb2a	CFz2p	CFz2a
Average	0,2494	0,4845	0,3493	0,4985	0,5157	0,6076	0,5164	0,8816
Std. Dev.	0,0311	0,0311	0,0618	0,0461	0,0652	0,0171	0,0955	0,0583
Err.max	0,0272	0,0272	0,0542	0,0404	0,0571	0,0150	0,0837	0,0511
Max	0,2766	0,5117	0,4035	0,5388	0,5728	0,6227	0,6001	0,9326
Min	0,2221	0,4572	0,2951	0,4581	0,4586	0,5926	0,4326	0,8305

Table 59. Two-way analysis of variance initial deformation (mm)

SUMMARY	2p	2a	Total			
Fb						
Count	5	5	10			
Sum	1,2468	2,4223	3,6691			
Average	0,24936	0,48446	0,36691			
Variance	0,000966	0,000965	0,016212			
Fz						
Count	5	5	10			
Sum	1,7465	2,4923	4,2388			
Average	0,3493	0,49846	0,42388			
Variance	0,003825	0,002123	0,008824			
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0,016228	1	0,016228	8,238201	0,011106	4,493998
Columns	0,18457	1	0,18457	93,698	4,31E-08	4,493998
Interaction	0,009232	1	0,009232	4,686738	0,045858	4,493998
Within	0,031517	16	0,00197			
Total	0,241547	19				

Table 60. Two-way analysis of variance final deformation (mm)

SUMMARY	2p	2a	Total			
Fb						
Count	5	5	10			
Sum	2,5785	3,0382	5,6167			
Average	0,5157	0,60764	0,56167			
Variance	0,004248	0,000294	0,004367			
Fz						
Count	5	5	10			
Sum	2,5818	4,4078	6,9896			
Average	0,51636	0,88156	0,69896			
Variance	0,009128	0,003397	0,042614			
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0,094243	1	0,094243	22,08757	0,000241	4,493998
Columns	0,261221	1	0,261221	61,22214	7,39E-07	4,493998
Interaction	0,093339	1	0,093339	21,87571	0,000252	4,493998
Within	0,068268	16	0,004267			
Total	0,517071	19				

Table 61. TUKEY'S multiple comparison test (TUKEY'S HSD) - pair-ways comparison between means for initial deformation. statistically significant differences are high-lighted (p<0,05)

Groups		CFb2p	CFb2a	CFz2p	CFz2a
	Average	0,24936	0,48446	0,3493	0,49846
CFb2p	0,24936				
CFb2a	0,48446	0,2351			
CFz2p	0,3493	0,09994	0,13516		
CFz2a	0,49846	0,2491	0,014	0,14916	

Table 62. TUKEY'S multiple comparison test (TUKEY'S HSD) - pair-ways comparison between means for final deformation. statistically significant differences are high-lighted (p<0,05)

Groups		CFb2p	CFb2a	CFz2p	CFz2a
	Average	0,5157	0,60764	0,51636	0,88156
CFb2p	0,5157				
CFb2a	0,60764	0,09194			
CFz2p	0,51636	0,00066	0,09128		
CFz2a	0,88156	0,36586	0,27392	0,3652	

Discussions

Overall, the results suggested a significant difference between the load-bearing capacities of the bridges with adjacent fibres cross-sectional design and of those with parallel disposition of the fibres. This difference might become even more evident in the case of higher pointed cusps, when the fibres could better support the composite that is transversally stressed by the horizontal component of the forces decomposed on the cusp slopes. The adjacent disposition of the fibres might prevent in some extend the delamination of the composite on buccal and facial sides of the pontic (Fig. 53). To the best of our knowledge, this type of cross-sectional design was never mentioned in the literature. It is more suitable for braided polyethylene fibre types which are easily spreadable, covering a bigger surface of tensile surface of the pontic. This architecture extends the results obtained in a previous study on ISO type bar specimens [257].

Saygili et al. analysed the effect of glass and aramid fibres position on the flexural strength of temporary restorative materials. Composite materials reinforced with glass fibres have shown a high transverse strength and a bending strength of 20-50% higher than those reinforced with aramid fibres [288]. The mechanical properties of polymer-based materials present both macroscopic behavioural and molecular behavioural aspects, including chemical composition and physical structure. The main mechanical test methods used provide information on compressive strength, flexural strength, modulus of elasticity and fatigue strength. The results obtained from these tests can provide information on patterns of destruction and ways of improve [289].

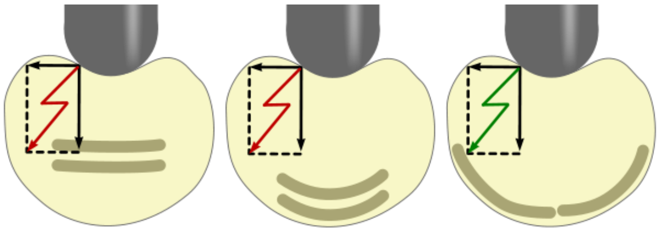


Fig. 53. Fracture pattern according to the fibres disposition

Compared to traditional dental materials, reinforced composites have complex properties. If the metallic alloys are uniform, homogeneous and isotropic (they have the same properties regardless of the direction in which they are loaded), the reinforced composites are heterogeneous and anisotropic, which means that their properties are dependent on the direction in which they are loaded in relation to the orientation of the fibres. Mechanical, optical, thermal properties and curing shrinkage of the FRC are dependent on the fibre quantity and orientation [290, 291].

For composites reinforced with unidirectional (long, continuous and parallel) fibres, the best properties are recorded when the direction of the force is parallel to the direction of the fibres, and the weakest are in the direction perpendicular to that of the fibres [160, 257].

The resistance of fibre-reinforced composites is correlated with the fibre reinforcement efficiency (Krenchel factor), which is significantly influenced by the orientation in plane of the fibres [292, 293].

For composites reinforced with unidirectional fibres, the factor has the highest theoretical value when the direction of force is parallel to the direction of the fibres and the value is null when the stress of the material occurs in the direction perpendicular to the direction of the fibres. The perpendicular orientation of the bi-directional fibre reinforcement is expressed by a factor of 0.5, this reinforcement efficiency being twice the bi-directional fibre at an angle of 45° in the direction of force. In the case of short, discontinuous fibres, the Krenchel factor value is 0.38 [289].

As a result, the restoration and design of its components must be correlated with the biggest loads direction. For example, in the case of a dental bridge, in the region of the pontic most of the fibres have a mesial-distal orientation and only a few fibres are oriented in other directions [160]. Some authors recommend placing additional fibres to prevent fracture of the composite veneer, especially when fixed prosthetic restorations are in the lateral area. Studies on the viscoelastic behaviour of FRC with glass have shown that they have a value close to that of dentine (15.32GPa / 17 GPa) [294].

The clinical performances of FRC restorations are tributary to the continuous improvements of materials structure (fibres, resin matrix and fillers), adhesion protocols, new technologies (CAD/CAM) and, consequently, new design principles, opening preclinical and clinical alternative research directions [164, 190].

In some regards, the testing of the specimens in this study can be considered as extreme. The concentration of the forces in one loading-point and the absence of physiological periodontal resilience are among the factors altering the results. Intra-orally, through a distributed dispersion of the occlusal forces along the dental arch, the fracture pattern might be modified. Even in this context, the adjacent disposition of the fibres in the pontic should improve the mechanical behaviour to the transversal forces, frequently encountered in oral conditions.

Clinically, the dental restorations are subjected to masticatory forces ranging between 500 and 900 N in the molar region [295], but according to DIN standard, the FDPs have to withstand forces which exceed 1000N in static fractures tests [166, 273, 295]. The tested samples in this study withstood forces higher than 1300 N for the adjacent disposition of the fibres, which make them suitable for clinical application. The periodontal resilience might allow even a superior load-bearing capacity of the FRCBs, without deformation, except in case of occlusal trauma.

One important factor contributing to survival-rate of FRCBs is the inter-abutment distance, related to the amplitude of the pontic. A reduction of 25 to 35% of the fracture strength was recorded in case of increasing the pontic from 7 to 11 mm in the case of inlay-retained FRCBs [296]. The different specimen dimension is one of the many factors which make that the comparison of other studies results to be difficult or inconsistent.

Other factors are: methodology, employed materials, fibre thickness, location and orientation [207, 271-273].

An interesting finding of this study is that there were no failures in the form of debonding proving the existence of a strong adhesive interface able to resist the occlusal forces.

The relatively small sample size might be the most important limitation of this study. It could be reason for not finding significant differences between the two tested composites – Filteck Z250 and Filteck Bulk Fill.

Another limitation of this study is that the specimens were not subjected to thermocycling and fatigue testing with water immersion, as supplementary conditions for estimating the mechanical behaviour in vivo conditions [272, 297].

Conclusions

Within the limitations of this in vitro study, the following conclusions could be drawn:

- Both parallel and adjacent cross-sectional design proved to withstand forces higher than 1000 N until the initiation of the fracture.
- The load-bearing capacity of the bridges with adjacent fibre disposition increased comparing with those with parallel disposition of the reinforcing fibres.
- The adjacent disposition of the braided polyethylene fibres at the pontic tensile surface might prevent the delamination of the composite on buccal and facial sides of the pontic.

2.2.3. BIOMECHANICS OF PROSTHODONTIC RESTORATIONS BY FINITE ELEMENT ANALYSIS

2.2.3.1. State of art

The oral environment presents a distinctive attribute – the occlusal stress, making the dental care one of the domains where the mechanical testing is of paramount importance, placing the dentistry next to aerospace, civil engineering and automotive industry.

Specific issues raise, in the domain of dental biomechanics, the complexity of the oral environment making difficult to transpose and replicate the conditions in lab experiments. The live experiments are time-consuming, expensive and highly ethically questionable.

Virtual models and simulations have emerged as a reliable alternative allowing a computational iterative optimization of the experiment design by virtual repeated testing and evaluation. The final design is transferred to live experiment, saving the time and the money usually used for intermediate design [298].

The finite element analysis (FEA) facilitates the assessment of deformations (strain and stress) of a large structure by dividing it in smaller elements for which is easier to calculate the individual deformations. Computing simultaneously the deformations for all elements, the final deformations for the whole system can be assessed.

Lately, in the field of dental medicine and especially in those areas where biomechanics conditions the therapeutical procedures, an increase in the volume of scientific work that demonstrates this approach has been noticed. This tendency is most encouraging provided that the reader has the required knowledge to allow him to understand the analysis.

One of the shared features of enamel and dental materials, like composite and ceramic, is their brittleness. Fracture is one of the most frequent mechanical breakdowns of these materials and, even when not catastrophic, it leads the way to failure. The number of finite element analyses conducted on dental restorations is constantly increasing, but only few of them incorporate the brittle failure phenomena [299]. Most of them use the von Mises stress to determine if a material will yield or fracture which is typical for ductile materials, such as metals [300].

Using the traditional biophysical knowledge database in a rational validation process [301], the use of FE analysis in dental research has been significantly refined during the last two decades [302-304].

However, for typical finite element method (FEM) it is difficult to efficiently incorporate a failure criterion and simulate damage driven continuum-to-discrete process, which are required to model fracture phenomena.

My interest and abilities in 3D modeling and FEA were reflected in multiple collaborations with PhD students during their doctoral studies, supporting and completing clinical observation and laboratory results obtained in their research. The results were presented as oral communications or posters and published in volumes at prestigious scientific events or prestigious journals.

The directions of my research by 3D modeling and FEA were related with my domain of interest, prosthodontics, encompassing:

- the impact of occlusal trauma inducing cervical lesions (Fig. 54) and periodontal lesions and (Fig. 55),
- single-unite restorations as inlays (Fig. 56), all-ceramic crowns (PhD research) (Fig. 57) and metal-ceramic crowns (PhD research) (Fig. 58),
- fixed dental prosthesis and
- removable partial dentures (Fig. 59).

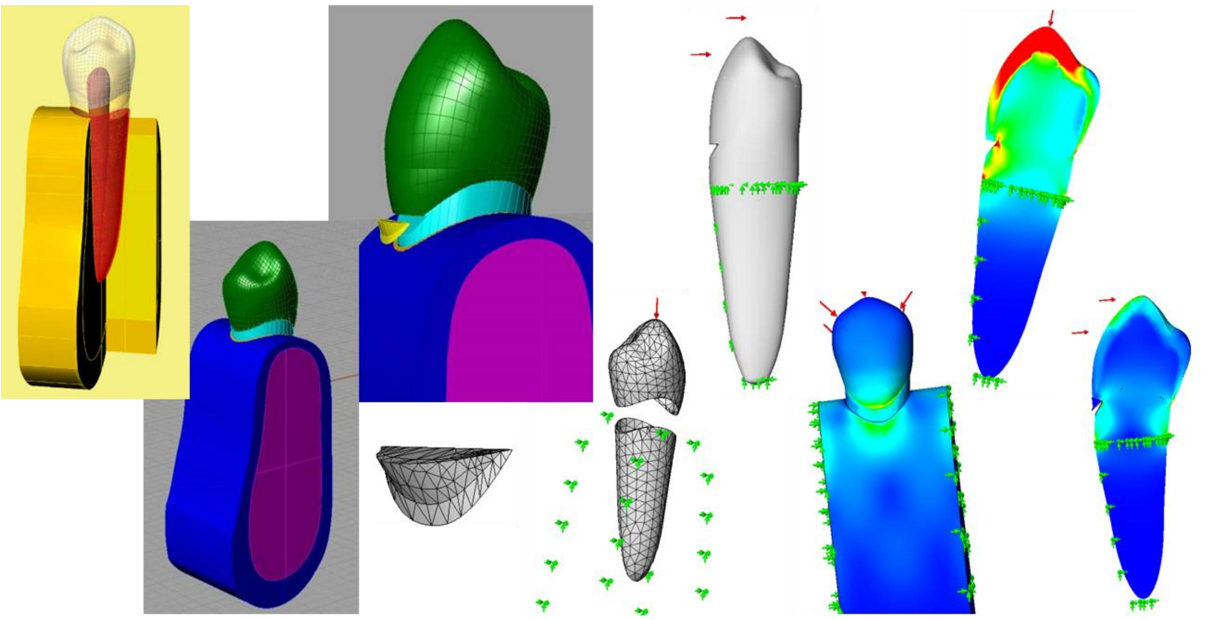


Fig. 54. Finite element analysis in cervical non-carious lesions

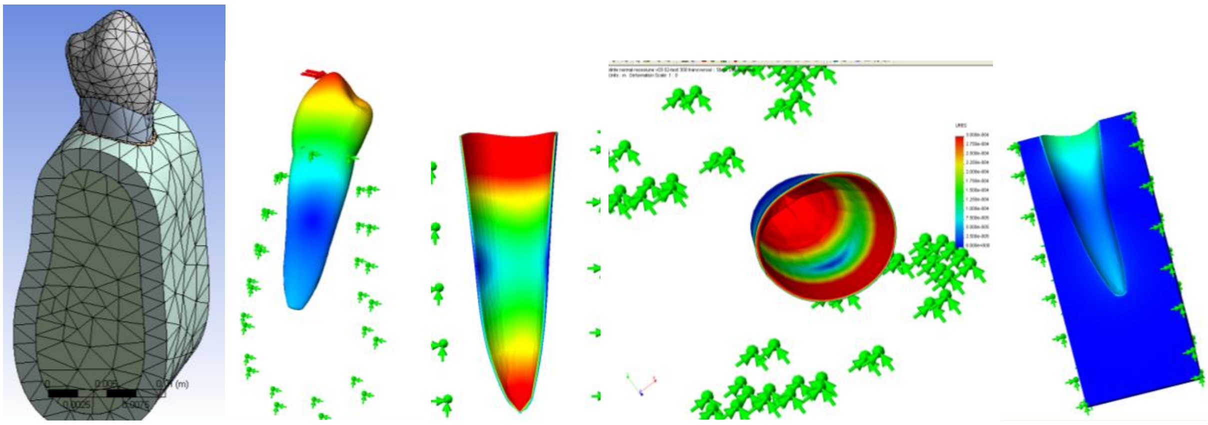


Fig. 55. Finite element analysis of tooth-supporting tissues

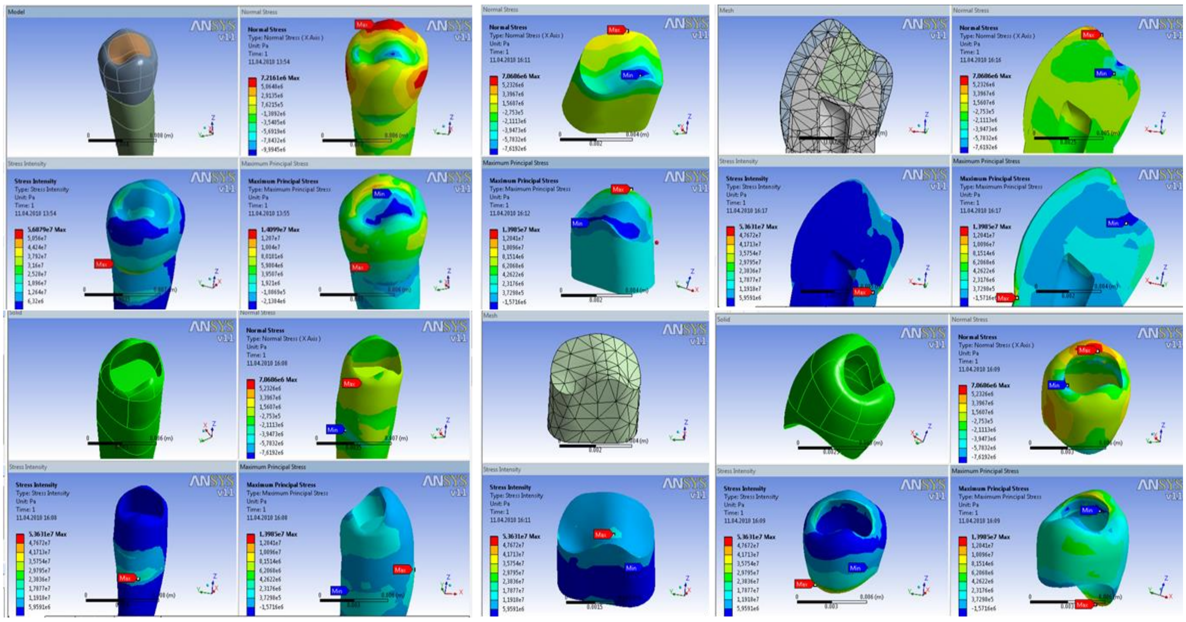


Fig. 56. Finite element analyses of biomechanical behaviour of different type of inlays

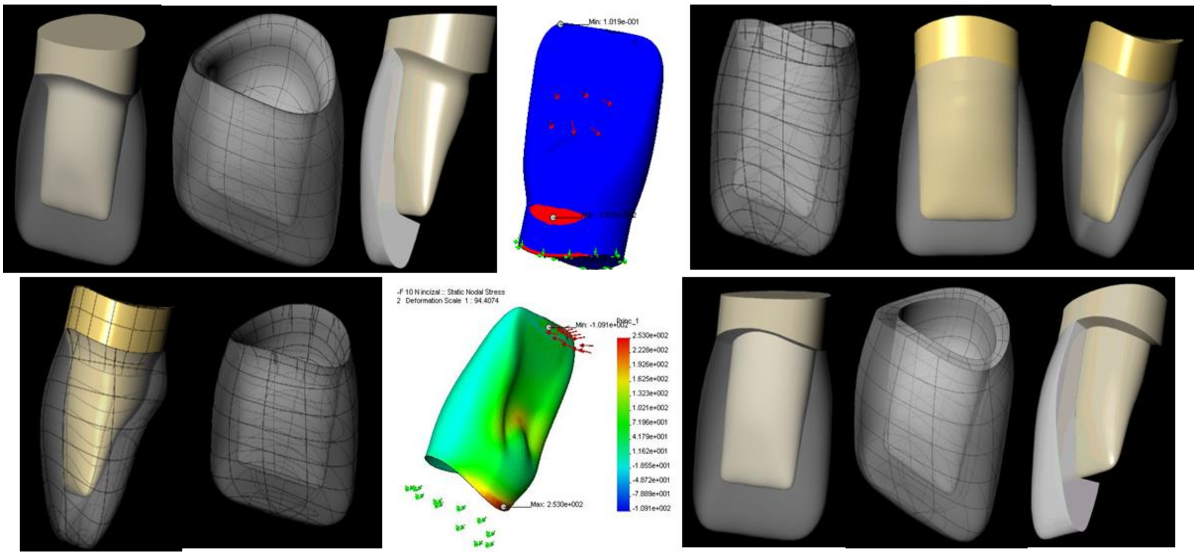


Fig. 57. Finite element analyses of biomechanical behaviour of different types of crown margins

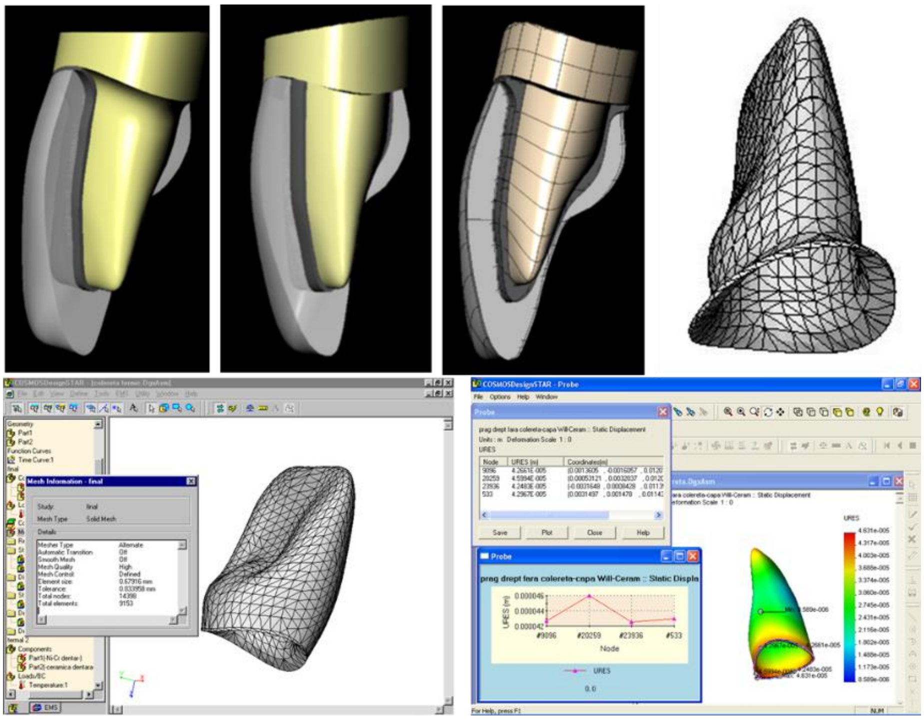


Fig. 58. Finite element analyses of firing behavior of metal-ceramic crown margins

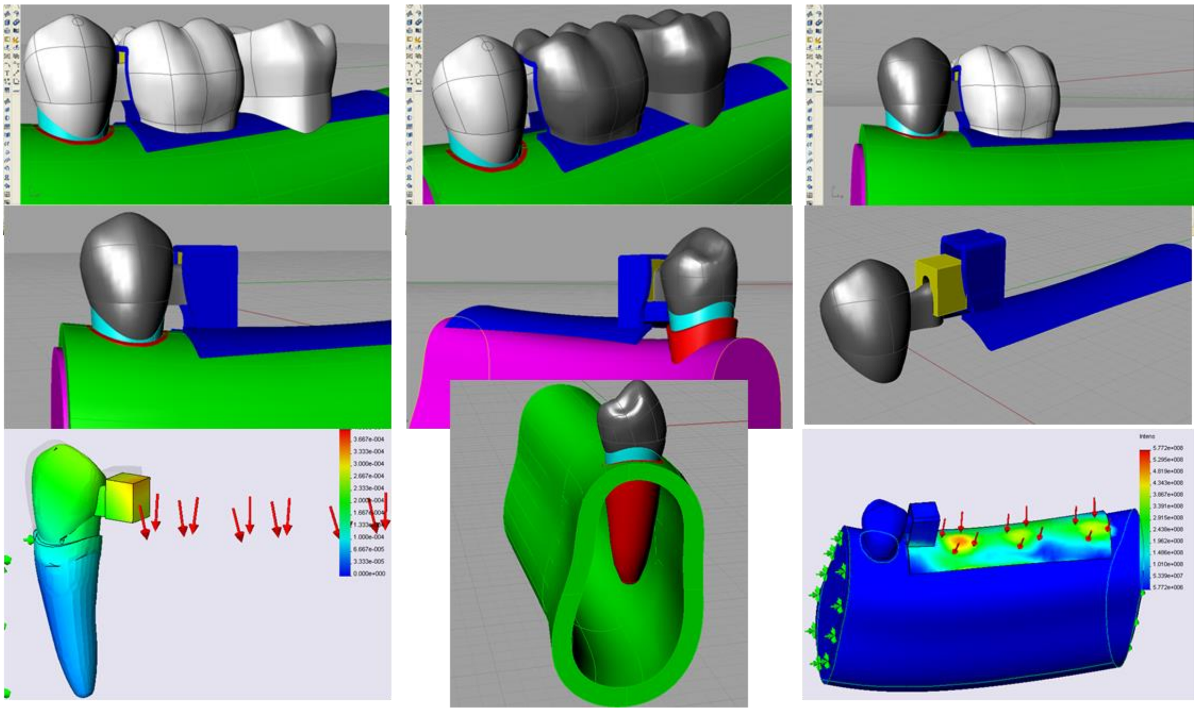


Fig. 59. Finite element analyses of biomechanical behaviour of cast metal framework removable partial dentures

The fixed dental prothesis (FDP) induces adaptative modifications in support periodontal tissues. The functions of the stomatognathic system are possible due to mandibular dynamics with and without dental contact. The FDP are subjected to loads with different directions, points of application and intensities. The prosthodontic therapy is depending on periodontal health and on biomechanical and biological principles that guide the clinical and technological stages, including the choice of the restoration materials [305].

Regardless of the type of prosthodontic restoration chosen to restore the functionality of the stomatognathic system, there is always a response of the dento-periodontal support because of the stress resulted from the activity of the entire system. Evaluations of stress distribution of FDPs have been conducted with FEA in many studies [306-310].

Most relevant personal scientific contributions in this field (the highlighted papers are presented in extenso in the next chapters):

IDB

1. Ţănculescu O, Doloca A, Iovan G, Ichim I. *Biomechanical study of class I inlay restorations and luting cements behavior - a 3D-FEA study*. Journal of Romanian Medical Dentistry, 2008, 12(3):35-42, ISSN: 2066-6063 ijmd_volume12_issue3_Oana-Tanculescu.pdf
2. Pendefunda V, Pendefunda-Ciocan A, Ioanid N, Apostu A, Ţănculescu O. *Finite element analysis of periodontal stresses in fixed prosthodontics*. Romanian Journal of Oral Rehabilitation, 2013, 5(4):82-87, ISSN 2066-7000 http://www.rjor.ro/finite-element-analysis-of-periodontal-stresses-in-fixed-prosthodontics-2/?lang=ro
3. Luchian I, Ţănculescu O, Rudnic I, Tatarciuc M, Mârţu S. *The analyze by finite element of strains in periodontal ligament and alveolar bone during orthodontic tooth movement* - Romanian Journal of Oral Rehabilitation, 2012, 4(1):35-40 The Analyze by Finite Element of Strains in Periodontal Ligament and Alveolar Bone During Orthodontic Tooth Movement – Romanian Journal of Oral Rehabilitation (rjor.ro)
4. Tufescu A, Pendefunda AAC, Beldiman A,Tanculescu O, Baciu R, Vasluianu R, Martu MA, Ioanid N. Stress distribution on the periodontal support of fixed dental prosthesis with pier abutment finite element analysis. Romanian Journal of Oral Rehabilitation. 2021; 13(1):322-327 https://www.rjor.ro/stress-distribution-on-the-periodontal-support-of-fixed-dental-prosthesis-with-pier-abutment-finite-element-analysis/
5. Ciocan-Pendefunda AA, Apostu AM, Antohe ME, Dascalu CG, Tanculescu O. Correlations between the long-span fixed dental protheses and periodontal tissues modifications. Romanian Journal of Oral Rehabilitation. 2021; 13(2):209-217 https://www.rjor.ro/correlations-between-the-long-span-fixed-dental-protheses-and-periodontal-tissues-modifications/

2.2.3.2. Biomechanical study of class I inlay restorations and luting cements behavior - a 3D-FEA study

Aim of the study

Regarding this subject, we set out to establish a series of guidelines concerning the utilization of luting materials for two types of inlays – ceramic and composite. The aim of the study was to emphasize the biomechanical behaviour of these restorations, of the underlying dental structures and of the luting materials used in the restorations. The analyzed luting materials were: the zinc polycarboxylate, the Fuji - glass-ionomer resin, and the Panavia resin-composite.

Material and method

We created the three-dimensional model of an inferior bicuspid consisting of enamel, coronary and root dentine and pulp chamber. At its occlusal surface a cavity was designed which corresponds to a class I Black inlay and to the luting material. The radicular cement was not taken into account in the model because of its insignificant influence for out study.

The design of the model was achieved in the Rhinoceros, Nurbs modeling for Windows, version 3.0 software on a Pentium IV, 3 GHz, 200 GB HDD, 1 GB RAM, Windows XP computing platform.

The thickness of the enamel layer was input as the average value calculated from the values given in the scientific literature [311, 312] That means the following values were taken into account for the cupids' tips: V – 1,3 mm, O – 1,1 mm and on lateral faces V – 1,2mm, O – 1,1 mm, M and D – 1,0 mm. The inlay has a depth of 2 – 2,5 mm and an inclination of the lateral walls of 5°. The thickness of the cement film is 0,1 mm. The stress analysis is realized by using the finite element method which is suited for analyzing biological structures as it allows a more detailed investigation of areas with a large variability in material properties and a complex geometry. The finite element analysis was conducted with the Cosmos DesignStar software. The discretization consists of 34364 nodes and 23922 elements. The material properties which were considered are the elasticity modulus and the Poisson constant. All the investigated materials were considered to be isotropic and with linear constitutive relations. The constants used are shown in the table below [313-317].

Table 63. Materials used in models of premolar and inlays

Material	Young's moduli	Poisson's Ratio
Enamel	84.1	0.33
Dentin	16.7	0.31
Empress ceramic	96	0.19
Composite	21	0.24
Composite resin	18.3	0.35
GIC Fuji	4	0.3
Zinc phosphate cement	22.4	0.35

The use of constraints and loads define the conditions in which the model's mechanical behaviour is investigated. The contact angle depends on the occlusal morphology. In humans, the mastication force is known to be 500N in the molar region and 100- 200N in the incisor's region. The maximal axial stress is 70-150N. Higher levels of these forces are encountered in patients affected by bruxism. The occlusal stress in these cases can go up to 1000N [305, 318-321]. Due to its dynamic nature, the real stress in the masticatory process is difficult to assess [305]. Because of the dispersion of these forces, a unitary stress model was taken into account, so that a linear parametric analysis can be performed. This unity presents horizontal (lateral) and vertical (axial) components applied at the contact point. In our case, the fix zone was considered to be the dental root and the action forces were 400N applied in the center of the restoration. We choose this magnitude of the force as being in between the upper physiological limit of 300N where the periodontal alterations are reversible at an axial application, and the value of 500N which is reported by some authors to be related to bruxism affected patients [322].

Results

After inputting all the data, the software solves the differential equations that describe the studied physical process. The biomechanical behaviour of the tooth-restoration assembly is a consequence of the vertical and lateral components of the occlusal action force.

The results can be displayed as a colour coded diagram or as an alphanumeric table. The interpretation of these results makes use of the in-depth knowledge of the mathematical model of the analysis of the material stress theories (von Mises, Mohr-Coulomb, etc.) that will guarantee a correct and precise outcome of the study.

In the images produced by the analysis, compression areas around the force application point and the support zone can be observed. Areas of stretching and compression can also be observed at the cervical level, oral and vestibular. This confirms the clinical findings that if not correctly made, restorations can act as wedges leading to cusps fracture.

The composite inlay performed better that the ceramic concerning the stress dissipation ensuring also a better tensile strength. We noticed that the composite material exhibits an improved resilience that supports the stress transfer throughout the dental mass. However, its utilization has some drawbacks related with its toughness and low fracture strength.

The ceramic inlays transfer the stress to the dentinal walls and, depending on the rigidity, to the luting cement layer. In the case of high elasticity modulus cements, the inlay was not able to disperse the stress to the cavity walls while the composite was able to do that. We found that the restorations and the low elasticity modulus cements can partially absorb the deformations under load and limit the intensity of the stress that transmitted to the dental structures.

Another important observation that can be made is that the ceramic inlay concentrates the stress inside the material while the composite inlay transfers it to the dental tissues. Therefore, the increased internal tensions inside the ceramic inlay are due to a high elasticity modulus, which is higher than for the composite. The latter exhibits a lower internal tension.

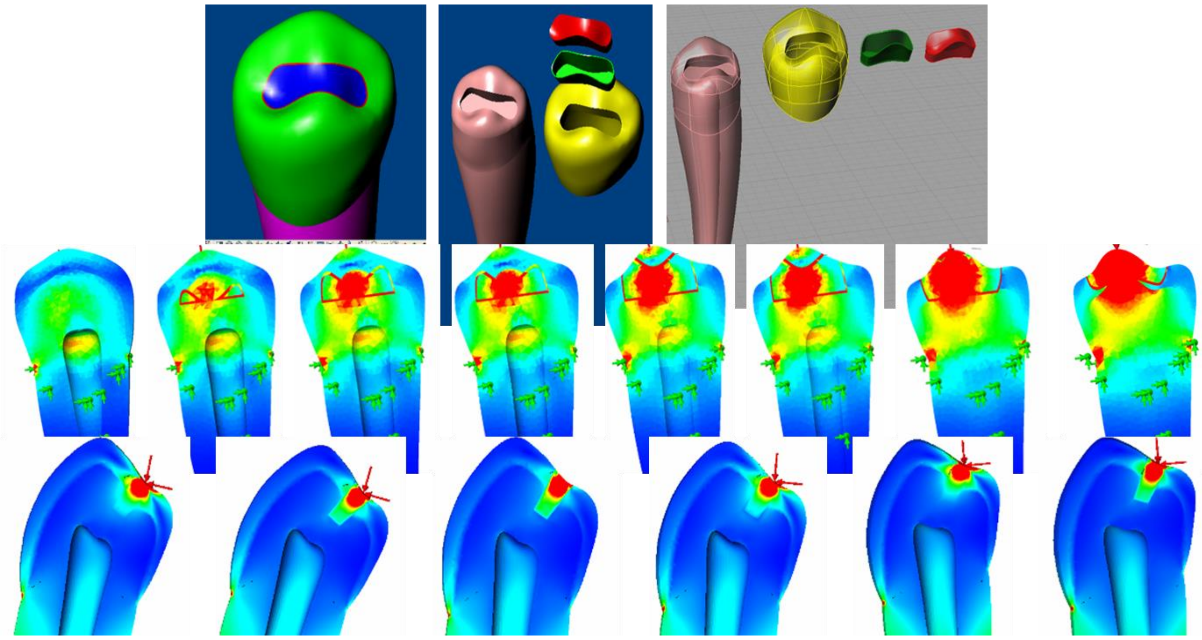


Fig. 60. The 3D models and FEA analysis

It can be noticed that by increasing the elasticity modulus of the cement from 4GPa (GIC Fuji) to 22,4 GPa (zinc-phosphate cement) the maximum values of the maximum principal stress decline gradually. Hence the lowest stress in the dentine has been observed in the case of the Panavia composite luting resin or in the case of zinc-phosphate luting cement.

The intensity of the maximum principal stress and of the von Mises tensions in the luting material grows together with the elasticity modulus of the cement. Among the used luting materials, the Fuji glass-ionomer and the zinc-phosphate cement have a low adhesion capacity, but Panavia has a good adhesion capacity to enamel, dentine, composite, ceramics and even metal.

The elasticity modulus is considered to be the most important factor in dissipating forces to the restorations. The dental structures perform better when the luting cement has an elasticity modulus similar to the one of the underlying structures on which it is fixed (dentine/enamel). This way the optimal biomechanical compatibility is attained.

The cement induced stress depends on the elasticity modulus: when a restoration is fixed using a cement with a much lower elasticity modulus then that of the dentine, then dental structures and the restoration itself cannot deform the same way. Therefore, the maximum principal stress and the von Mises tensions in the dentine are high. This is due to the fact that the dentine can withstand a higher load without deforming. When the elasticity decreases, that is the elasticity modulus increases the deformation strength increases as a consequence. The cement withstands a part of the static load and thus the maximum principal stress drops.

When the elasticity modulus is close to that of the dentine, the cement and the dental structure have similar deformations dissipating and distributing in a uniform manner the stress inside the dental structures and reducing therefore the maximum load areas. When the cement elasticity modulus is over 16,4 GPa the deformation strength is greater than the tooth's which leads to a concentration of the occlusal force and thus to the fracture of the luting cement.

Discussions

The results of this study support the already confirmed theory that the inlay luting material should be similar to the structures on which it is mounted. Hence the specialists choose instead of hard cements, ones that have almost the same properties to dentine in order to create a bio-functional unity. Regarding the zinc-phosphate cement, despite the fact that the elasticity modulus is relatively close to the one of dentine and the area of stress concentration is small, the restorations that use this type of material fail because of the high elasticity modulus and also because of the frailty and of the low adhesion to dentine, enamel, metal ceramics and composite.

Due to the fact that the form and depth of the restoration has a big influence on the obtained values, our results cannot be compared directly with other results given in the literature. However, the study shows the importance of the luting cement rigidity in the ability to dissipate the stress to the dental structure. This property is related with both the thickness of the material and elastic modulus, the latter being more effective on stress concentration [323, 324].

High elastic modulus materials accumulate stress and low elastic modulus materials absorb stress [323, 325, 326]. As found in our study, the ceramic (high elastic moduli) proved higher stress values inside the material and did not transfer it to the dental tissues. High amount of stress transferred to the tooth structure may be detrimental to crown and root, leading to fractures. High amount of stress absorbed by the restoration material may be detrimental to this, leading to higher failure rates of the restoration, but potentially preserving the tooth structures.

It has been reported that adhesive indirect composite restorations absorb the stress initially for an immediate transfer to the tooth, thus the restoration - tooth complex accumulates energy until failure[323, 327]. Also, previous finite element studies indicated composite resin yielded lower risks of root fracture and higher elasticity modulus materials tend to transfer stresses to the deeper part of the root [328].

According to some researchers, the ceramic inlays reduced tension at the dentin-adhesive interface, improving the bonding resistance comparing to composite inlays [329, 330]. Similar results were obtained in this study. On the other hand, other researchers found that ceramic restorations created higher stress levels at the internal surfaces of the preparations [313, 331] and also that the composite inlays prove similar biomechanical properties as the tooth and redistribute stresses [332].

In any circumstances, it seems that the resin luting agents employed in the indirect technics reduce to some extent the stress concentration, but not sufficiently to absorb the stress [333].

At the moment the study was conducted, the novelty and the challenge of this study resided in the fact that it was based on three dimensional models having a morphology that follows with high precision the clinical reality. This method brings advantages as well as disadvantages. The more complex the model is the higher the probability of an error. The challenge is to identify these errors and to eliminate them as much as possible. Other limits of the study were the following: the loading type was assumed unique, the dental tissues are unisotropic but assumed to be isotropic and the adhesive failure was not processed.

Another downside that we encountered at the time was the limited processing power of the used computers. A 3D model with the necessary complexity to reproduce the organic substructures including the periodontal ligament and the restoration itself demands a considerable computing power. This is also why research in this field using these methods was, at that time, quite scarce. The utilization of numeric systems for biomechanical research was relatively new the first studies being published in the '70s. The areas where cooperation between engineers and specialists in medical fields was developing were orthopedics and dental medicine. This lies somewhere between the mechanics of the solids and that of the fluids. Presently research is focused on analysis using the finite element method to identify solutions to actual problems in the dental field. Therefore, identification of the model parameters (stress, tissular characterization) is sought through numerical techniques.

Conclusions

1. Three-dimensional model design and analysis through finite elements allow the investigation of a virtually unlimited number of combinations created by using various parameters. This leads in fact to a large number of models.
2. A major advantage of the method is that of the visualization of the tensions that appear inside the dental structures.
3. One of the factors that influence the success of the inlay therapy is the luting material.
4. The best biomechanical behaviour was found using the composite Panavia resin.
5. From the biomechanical point of view the poorest results were found with the Fuji glass-ionomer.
6. Despite the findings, the utilization of the zinc phosphate luting cements is not recommended because of the low adhesion to the substructures and because of the low fracture strength.

2.2.3.3. Correlations between the long-span fixed dental protheses and periodontal tissues modifications

Aim of the study

The purpose of this study is to determine by finite element analysis (FEA) if there are correlations between periodontal modifications and the long-span FDPs in the context of various location of occlusal load.

Material and methods

The evaluation in vivo or in vitro of the forces acting on the periodontal ligament is quite difficult to be carried out. Finite element analysis can provide useful information on stress distribution, specific deformations and displacements of the ligament and bone [334, 335]. In this regard, four-unit pontic FDP with two cover crowns as retainers was tested. The edentulous space was in the left lower quadrant, from the first premolar to the second molar and abutment teeth were the canine and the third molar.

The following aspects were considered:

1. biomechanical evaluation of the periodontal ligament
2. biomechanical evaluation of the mandibular bone
3. establishing the role of occlusal forces on the biomechanical behavior of the periodontal ligament
4. FEA analysis of stress distribution, specific deformations and displacements at the periodontal ligament.

For a proper simulation of the biomechanical phenomena, the geometric model needs to be as close as possible to reality [309, 335]. In this sense, the 3D reconstruction included the mandibular bone, the teeth – from lateral left incisor to third right molar, the prepared abutments, with their periodontal ligament, the FDP with the pontic and retainers. The three-dimensional reconstruction was made in AutoCAD 2009 software (Fig. 61), and the mesh in Algor 15 FEMPRO software (Fig. 62).

The considered material properties were the modulus of elasticity, the Poisson's ratio and the density of the material. Nickel-chromium alloy was chosen as material for the FDP [313-317] (Table 64).

As load application, the resultant of masseter and medial pterygoid muscles contraction during mastication was considered. The force value was 350N and the orientation was 150º upward and forward relative to the horizontal plane (Fig. 63). As boundary conditions, the top of the condyles was fully fixed. The action of the forces developed by the masticatory muscles generates, during mastication, reaction forces at the level of the temporo-mandibular joint and in the area where the FDP is in contact with the food. At the level of the FDP, the following situations were considered (Fig. 64):

a. contact on the area corresponding to the missing first molar,
b. contact on the area corresponding to the missing second premolar,
c. contact on the area corresponding to the missing second premolar,
d. contact on the area corresponding to the missing first premolar.

Table 64. Material characteristics for each component of the analyzed structure

Component	Modulus of elasticity (MPa)	Poisson's ratio	Density (Kg/m^3)
Bone	14200	0,33	1450
Dentine	13800	0,31	1900
Periodontal ligament	11,8	0,45	1250
Ni-Cr Alloy	207000	0,31	8931,7

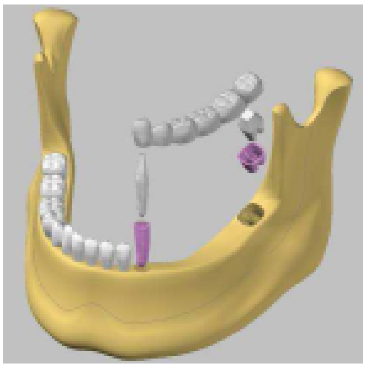


Fig. 61. The 3D model for the mandible, abutments and their periodontal ligaments, and FDP

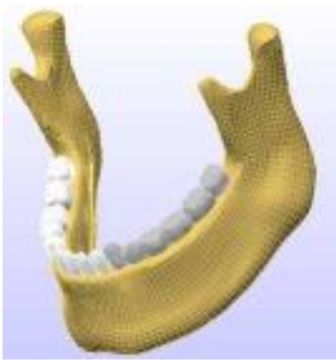


Fig. 62. The mandible and FDP model

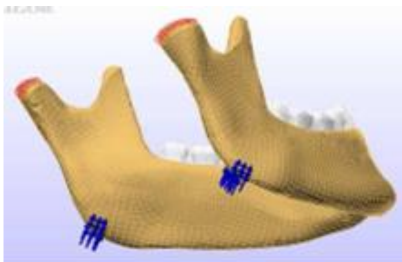


Fig. 63. Applied forces corresponding to masseter and medial pterygoid muscles

Results

The periodontal ligament is the main element of the periodontium and consists of collagen fibres embedded in the lamina dura and cementum providing support for the teeth during functions. For this situation, the highest recorded tensile stress, higher than 75 MPa, is found at the level of the FDP, in the connectors area. This can be explained by the large distance between the abutment teeth, the resulting of a high bending moment at the point of constraints application (contact with the food) and implicitly the appearance of a high tension it the pontic (Fig. 65).

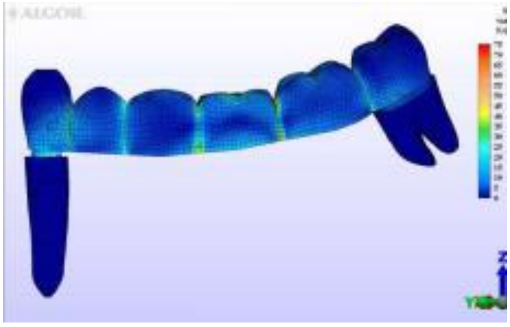


Fig. 64. Tension distribution for the FDP - abutment - periodontal ligaments assembly, when the constraints are on the first molar

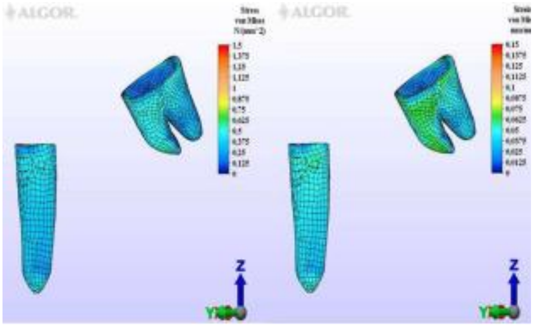


Fig. 65. Distribution of strain (left) and specific deformations (right) for the abutments periodontal ligaments when the constraints are on the first molar

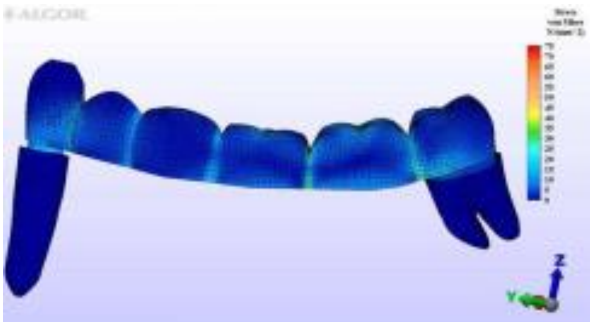


Fig. 66. Tension distribution for the FDP - abutments - periodontal ligaments assembly when the constraints are on the second molar

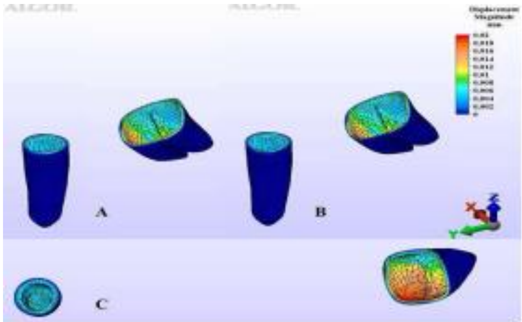


Fig. 67. Deformations at the level of the abutment periodontal ligaments, when the constraints are on the second molar: A - unstrained ligament; B – ligament strains; C- top view of the ligament strains distribution

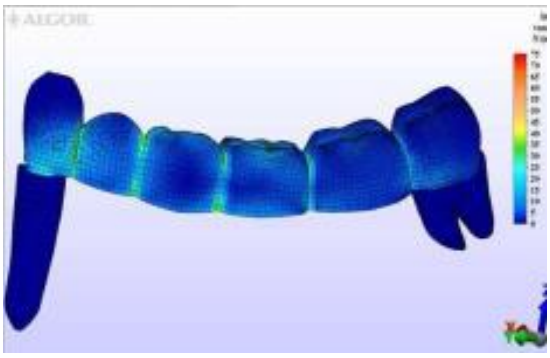


Fig. 68. Stress distribution for the FDP - periodontal ligaments - abutments assembly, when the constrain is on the second premolar

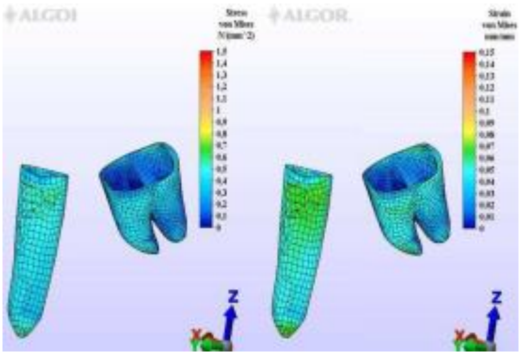


Fig. 69. Distribution of stresses (left) and specific deformations (right) for the abutment periodontal ligaments, when the constraint is on the second premolar

Although in static tensile test the FDP pontic is subjected to a tension below the maximum tensile strength, in dynamic loading conditions, specific to mastication and due to mechanical fatigue, the cracks might appear leading to FDP failure.

a. Contact on missing first molar: The tension in FDP is localized in the mucosal aspect of the pontic, especially at the level of connectors where the maximum displacements are recorded, due to the pontic bending (Fig. 66). The ligaments were isolated and the distribution of specific stresses and deformations are analysed (Fig. 67). It is observed that the maximum tensile stress in the ligaments is 1.5 MPa, and the specific deformation is 0.15 mm / mm. There is a stretching of the third molar ligament in its distal area, while at the level of the canine the ligament deformation is in the tooth axis. This can be explained by the displacement of FDP toward the mandible due to the deformation of the ligaments and implicitly, by the shortening of the distance between the abutments on which the FDP is supported. This tension of the collagen fibres can lead to their rupture compromising the implantation of the teeth.

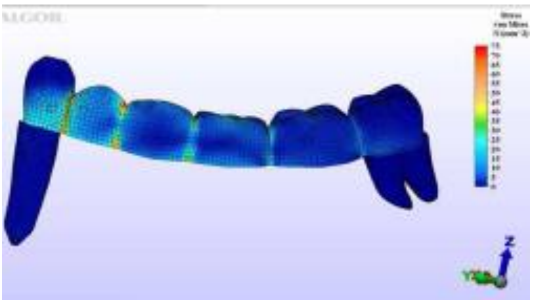


Fig. 70. Stress distribution for the FDP - periodontal ligaments - abutments assembly, when the constrain is on the first premolar

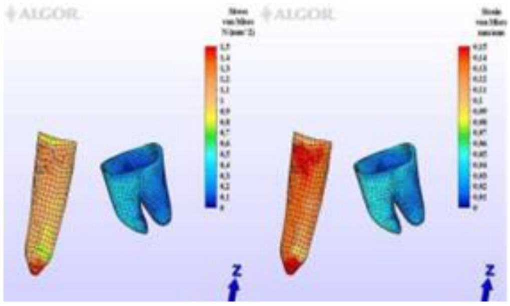


Fig. 71. Distribution of stresses (left) and specific deformations (right) for the abutment periodontal ligaments, when the constrain is on the first premolar

b. Contact on missing second molar: The tensions in this case are illustrated in Fig. 68. The maximum tensile strength was 75MPa, and tensile stress in the FDP are lower. The stress and strains are at the same values as in the previous case. The strains also have higher values at the level of the third molar, a high compression being found in the antero-lateral area accompanied by a tooth intrusion in the alveolar socket (Fig. 69).

c. Contact on missing second premolar: Compared to the previously analyzed situation, the tensions in the FDP are higher, because this time the load is closer to the canine inducing the maximum displacement (Fig. 70).

The specific tensions and deformations at the level of the two ligaments differ from the previous case, the highest deformation appears at the level of the canine, in the lateral area. The molar ligament is less solicitated because the load is closer to the canine and its implantation is more reduce compared to the molar (Fig. 71).

d. Contact on missing first premolar: In this case the maximum stresses in FDP are maximum at the level of connectors (Fig. 72). Regarding the specific tensions and deformations, they have a high level in the canine, because it takes over almost all the load developed by the resistance of the food. High value stresses are explained by the smaller transverse area than in the case of the other ligaments analyzed previously. In contrast, for the third molar ligament the specific tension and deformation decreases significantly, being protected in this situation (Fig. 73).

The displacements are quite large for the canine ligament, being 1.5 times higher than in the previous cases, which leads to the conclusion that even in this situation there can be a rupture of the ligament or of its insertion on the bone and cement.

Discussions

The function of the periodontium is to support the teeth during mastication. The vertical forces appear during mastication and deglutition, but also during certain parafunctions, and their intensity depends on the contraction force of the masticatory muscles, on the nature of the food and on the sensitivity degree of the periodontium. The tangential horizontal forces are transmitted through the contact points, permitting the distribution of the load to the adjacent teeth. The radial horizontal forces have a direction from the arch, being generated by the outwards tilt at the maxillary arch and the frontal region at the mandibular level. Each tooth has a limited capability of coping with occlusal forces which is mainly gave by the quality of periodontal tissues and tooth morphology, reflected in the implantation of the tooth. According to this, the specific biomechanical value of an abutment teeth is influenced by a multitude of factors. The teeth, the support periodontium and the implantation bone offer, from a mechanical perspective, a different resistance to the mechanical efforts they stand. From this point of view, pluri-radicular teeth show good implantation compared to mono-radicular teeth. The divergence of the roots increases the implantation value proportional to the area of the stabilization triangle between the apexes. The position of the teeth on the arch is a determining factor in the evaluation of the biomechanical competence of each dental unit, since each dental group has a well-determined function in the mandibular dynamics, a function imposed by the localization of each tooth on the arch and their morphology.

When partial edentulism occurs, the forces meant to be distributed to all the teeth are transmitted only to the remnant teeth. The balance between forces is disrupted leading to overloading of teeth, i.e., occlusal trauma. In this regard, fixed prosthetic rehabilitation of the premolars and first and second molar absence is a challenging task for dentist due to the considerable stresses and strains in the supporting tissues that varies based on different prosthetic designs [336-339].

The preoccupations for simulation, with scenarios that tend to reproduce as accurate possible the clinical context, are materialized in a constant increasing number of scientific publications. Styranivska and col. conducted similar studies, approaching various scenarios of simulating the forces induced by the masticatory forces at the level of fixed prostheses, with various degrees of amplitude of the dental bridge [340]. During a modelling scenario of partially fixed prostheses supported by the first premolar and the third molar, the maximum tension occurred in the connection points between the pontic and the retainers. The highest tensions were localized in the area of the distal tooth, reaching 190,88 MPa, while the lowest value of 29,94 MPa was recorded in the pontic of the fixed prostheses, where the load was applied.

Conclusions

Finite element analysis has shown that there is a correlation between the long-span FDP and the modifications of the periodontal ligaments of the abutment teeth according to the position of occlusal load. An overload of the periodontal ligament leads, implicitly, to the rupture of the ligament fibres, either in the ligament or in its insertion area in the cement and the bone, compromising the dental implantation. Fixed dental protheses with support on the canine and third molar have a long span for replacing the four missing teeth. Due to the large amplitude, it has an increased effect of flexion of the pontic accompanied by the overloading of the ligaments of the abutment teeth. To achieve a proper biomechanical balance, it is necessary to provide a dento-periodontal support capable of annihilating the demanding forces, which is not possible in this situation. This type of long-span FDP is contraindicated considering the negative effect induced in the abutment teeth.

2.3. SOFTWARE FOR MEDICAL DENTAL PRACTICE AND EDUCATION

Information technology penetrates various fields of activity, medicine being one of the most privileged. What is particular for medicine is its human dimension that can't be substituted by a computer. However, there are some activities in which the computer can take over some of the duties or can assist the practitioner during the medical act itself or auxiliary activities.

Computers and software have been used in dental medicine since 1960s [341] and, since then, we witness continuous development and progressive spread in dental practice. In 1986, Zimmerman et al. [342] was classifying the dental software as: for administration and management of patients' documentation, electronic archives of the documentation, telecommunication, computer - aided education, computerizing instruments and techniques in the dental office software assisting with clinical decision making. In general terms, this classification is still valid. Progresses in computer-based technologies including virtual reality (VR) simulators, augmented reality (AR) and computer aided design/computer aided manufacturing (CAD/CAM) systems have resulted in new modalities for training and practice of dentistry.

This chapter presents in its first part, some of our original software applications regarding administration, management and electronic archives of patients' documentation radiographic imagine processing and analysis and interpretation of clinical situation contributing to the decision-making process. The second part is focused on one of the most modern and efficient computer-assisted learning methods, the virtual patient concept, getting an overview picture of the most popular virtual patient software currently available, and presenting some examples of virtual patients authored with OpenLabyrinth, an open-source software.

2.3.1. ORIGINAL SOFTWARE FOR MEDICAL DENTAL EDUCATION AND PRACTICE

2.3.1.1. State of the art

Computer-based technologies play an important role in all aspects of our daily life as well as in dentistry. Modern Dental clinics practice Evidence based Dentistry (EBD), focusing on scientific research-based decision and, thus, revolutionizing the dental practice in modern times. Dentists who are up to date with scientific data, systematic reviews and meta-analysis perform better than their peers. Collecting the data needed for long-term observations and clinical trials is a challenge for some specialists and a real ordeal for the rest of them. Adding to this the need of scheduling the treatment plan and booking multiple appointments, the dentistry and the related activities become difficult to manage. Fortunately, dental practitioners can overcome this with the help of technology. Dentists and oral care providers can save time and provide adequate services and affordable treatment to their patients when equipped with the right tools. There are many dental practice management software available on the market - Dentrix Dental Systems (first practice management system for Windows - 1989), ACE Dental Software (2003), Denticon (2003), Curve dental (2004), DentiMax (2004), Vcita (2010), some of them being open-source – Spinnaker, Open EMR, OpenDental, Dentaltap, Practice Dent Lite, iKlyk, Dentsoftware.

Since 2002, I realized the potential and need of computer technology and its utility in daily activity practice but also in the educational activity, due to my double quality at that time:

young dental practitioner and teacher. Consecutively, I participated in the development of several computer applications, which appeared as a result of identifying some needs existing at that time. My first application software, *DentPrep* (2004), was created for helping the students and young practitioner in choosing the type of peripheral preparation on X-ray images, considering the clinical criteria and the technological considerations. The software was presented in my PhD thesis. For managing the specific activity of dental office and supporting the decision-making process, I participated in the development of two other applications: *Dental Suite* for adult patients (2006) and *PedoDent* for children (2009). SPINIT software was developed in 2009 following the introduction of a new method of testing students – MCQ and SCQ. *DSF - Software aesthetics*, developed in 2010, was dedicated to patient esthetic evaluation and decision-making process and will be presented later in this chapter. In 2008, I had the privilege to participate under the coordination of Prof. Dr. Norina Forna in elaboration of *Prodent*, an extensive software project dedicated to the specific activity in Dental Education Base for registering patients and archiving their records (2008).

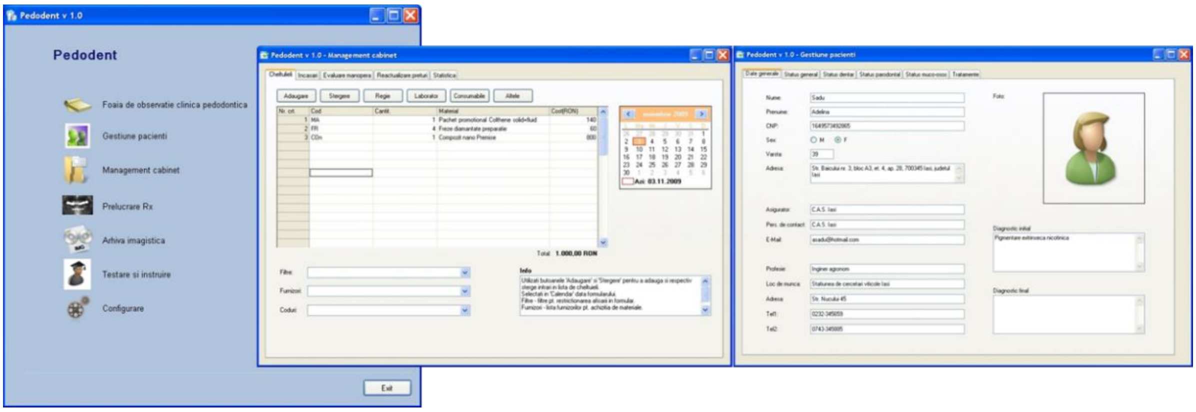


Fig. 72. PedoDent Software

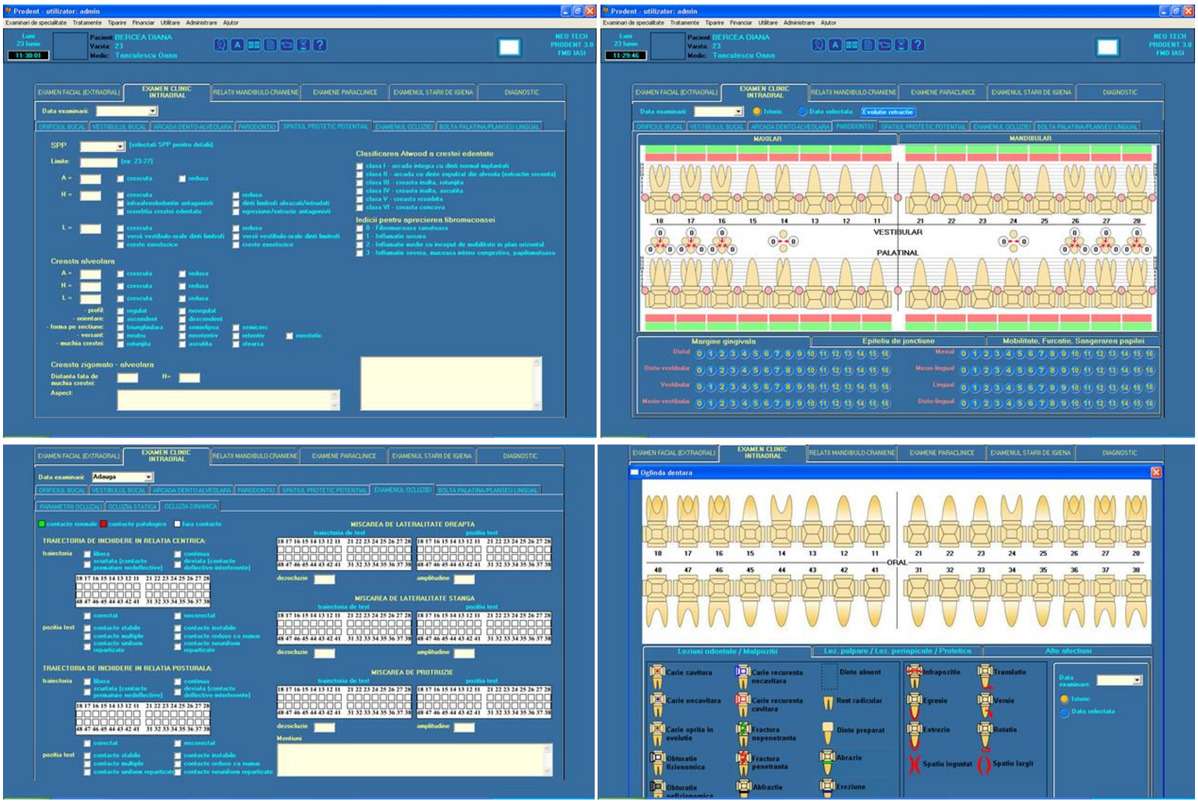


Fig. 73. ProDent Software

All our created software had a significant educational component, being a powerful learning instrument for our students, some of them supporting the dental office management activities also. At this moment, dental software is dedicated to a specific activity, either management or education and training, or design and manufacturing of dental prothesis.

	Most relevant personal scientific contributions in this field (the highlighted papers are presented in extenso in the next chapters)**:**
ISI	1. Doloca A, Ţănculescu O. *Floating License Management - Automation Using WebTechnologies*. International Journal of Computers Communications & Control 2011;6(4):615-621. ISSN 1841-9836. FI = 0,694/2011; 0,746/2014 http://univagora.ro/jour/index.php/ijccc/article/viewFile/2089/608
IDB	2. Ţănculescu O, Gavriluţ D, Doloca A, Gavriluţ A, Cliveti I. *Computer application for dental practice activity management*, International Journal of Medical Dentistry, 2005;9(4-5):94 – 99, ISSN: 1453-1224 https://ijmd.ro/wp-content/uploads/2019/07/ijmd_vol9_issue4_O.TANCULESCU.pdf 3. Ţănculescu O, Mârţu S, Cliveti I, Stroici C, Chirap I, Munteanu B, Doloca A. *Statistical Study on the Utilization of Information Systems in Dental Offices*. International Journal of Medical Dentistry, 2011, 15(4):7-12, ISSN: 2066-6063 ijmd_vol15_issue4_Oana-Tanculescu.pdf 4. Ţănculescu O, Ifteni C, Ifteni G, Cristescu C, Iordache C, Doloca A. *Computer Application for the Evaluation of the Dento-Somato-Facial Aesthetic Balance.* Romanian Journal of Oral Rehabilitation, 2012, 4(1):91-6, ISSN 2066-7000 http://www.rjor.ro/wp-content/uploads/2012-numarul-1-2012/Computer-application.pdf

2.3.1.2. Application software for dental practice activity management

Aim of the study

The aim was to respond to the existing needs, be creating a suite of computer application which cover some of the daily dental activities: editing the patient record, radiographic imagine processing and analysis, and interpretation of clinical situation.

Material and method

The software has been developed in Microsoft VisualBasic.Net. The .Net technology is the latest in computer program development and allows for rapid creation of the user interface and gives access to the latest internet development technologies. This aspect is very important considering the need to access the patient data from different locations.

Results

The software package is structured on 6 modules:

1. dental office management module – data bases for office management – employs, payments, expenses etc.
2. patient management module – data base storing information about appointments, payments, treatments
3. patients records - data base containing information about patient general and dental status, including clinical and radiographic images
4. radiographic image processing - either periapical radiograph or orthopantomography

5. static and dynamical diagram creation module for the case and the interpretation of RP vector
6. implant simulation – implant and prosthetic simulation using radiographic images

The modular structure of the software allows the user to quickly adapt to the various functions of the program. Furthermore, based on the necessities, only those modules that are required can be installed.

The program interface is user friendly and facilitates the access to the various functions and options that are offered by program. The organizing functions and patient data management as well as dental management functions are found in most existing software. What our software package brings as extra feature is the introduction of the following modules: radiographic image processing and optimization, static and dynamical diagram creation module for the case and the interpretation of RP vector and implant and prosthodontic simulation. Even the patient management module has an original approach, been based on the patient record form used by Gnatoprosthetic Clinic of the Faculty of Dental Medicine.

Discussions

Patient record

This module is designed using the patient record form structure from the Gnatoprosthetic Clinic of Faculty of Dentistry of U.M.F. Iaşi which, from our knowledge is the most comprehensive and complex one encompassing on the aspects of clinical and paraclinical examination intra and extraoral examination.

From the screen shots one can see that all the phases of the clinical examination are covered by the software the orientation towards comprehensive and detailed approach of the problem being obvious. This comes to the help of the practitioner, allowing him to quickly manipulate a large volume of information which is absolutely necessary and will guide him through therapy algorithm that fallows.

The input window for “general data” contains input fields to be filed with the personal data of the patient, motifs of presentation with description of the problem, personal and heredo-collateral general and dental history, life and working conditions, initial and final diagnostic which will be filed after all the clinical and paraclinical investigation is concluded.

This input form is for the extraoral examination and has sections for front and lateral facial inspection, superficial and profound palpation, and examination of TMJ. The input form for paraclinical examination collects information about the investigations on general state condition and investigations of TMJ, allowing observations about capsule, articular disc, ligaments, synovial lining, mandibular condyle and other constitutive elements.

For dental status view a special form was designed, in which characteristic data can be input for each tooth. By pressing the “radiography” button, the radiographic images can be accessed and displayed from a data base for each patient or tooth. The “intra-oral exam” window has input fields for required elements that can be observed and evaluated: lips, jugal mucosa, mouth opening, functional arias. Another element that needs to be observed during patient’s investigation is the occlusion, either statically or dynamically, considering the morphological and functional specific parameters.

The design of the treatment plan begins with the sanitary education and the general preparation, during which a psychological and drug prescription may be needed. Unspecific preparation is concerning dental and periodontal level, being recorded in special fields. Specific preparation is also evaluated and considered, and it addresses to teeth, periodontium, mucosa, bone, occlusal balancing, cranio-mandibular repositioning.

The recording of prosthetic phases is achieved step by step and, based on the user’s need, one or several windows can be activated, according to the prosthodontic devices or for each dental arch. The therapeutical solution will be recorded in the specific field, together with some observation which can be useful to dental technician or to the physician. Representation of the device sketch and the statical and dynamical diagram can be displayed as well as the images of the final clinical situation. This information can be saved, modified or printed out, obtaining patient record, which can be constantly updated.

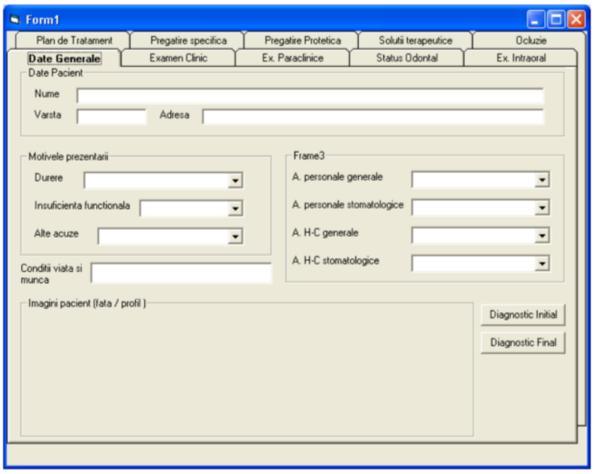


Fig. 74. "General date" interface

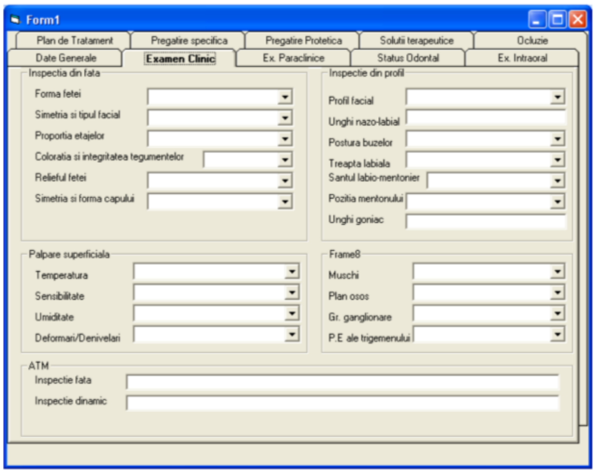


Fig. 75. "Extra-oral clinical exam" interface

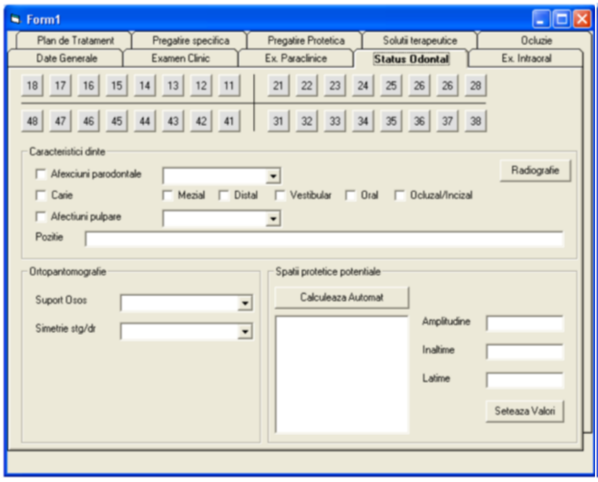


Fig. 76. "Odontal status" interface

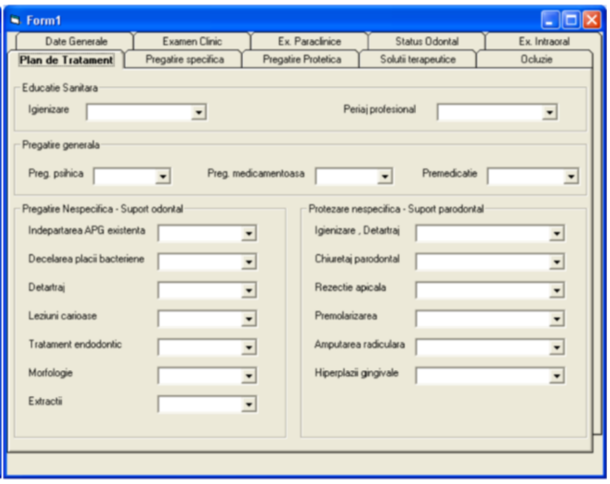


Fig. 77. "Treatment plan" interface

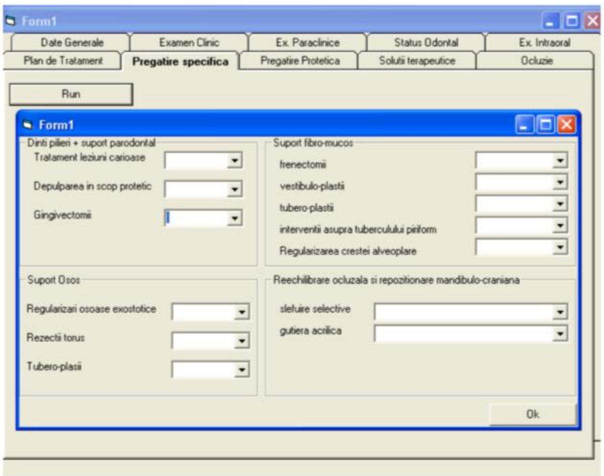


Fig. 78. "Specific preparation" interface

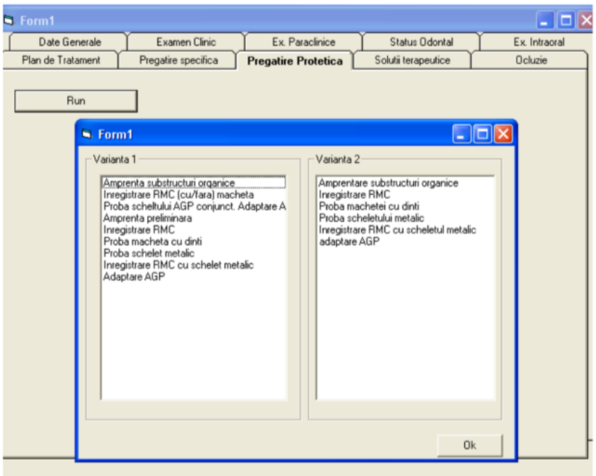


Fig. 79. "Prosthetic treatment" interface

Creating the static and dynamic diagram

The static and dynamic diagram guides the process of selecting the appropriate therapeutic solution, in compatibility with the biomechanical principles that governs the biological integration of the prosthetic restoration in the stomatognat system.

Each odonto-periodontal substructure is assigned a series of biomechanical competence indices according to the ability of response to the mechanical loads during the functioning of the system. Normally, this index is proportional to the insertion area of the periodontal ligaments on the root surface of each tooth. Thus, the teeth having multiple, well represented roots, have a higher index than the teeth with one thin root.

The principle of the static and dynamic diagram is to verify to what degree an edentulism can be biomechanically compensated by a prosthetic construction which is supported only by the teeth next to the edentulous space, or an extended support on the adjacent teeth or even on the opposite dental arch must be achieved.

The polynomial law certifies if a prosthetic construction is balanced from the static point of view or not. In this respect, the pressure on the “pillar-teeth” must be less or equal than their strength. The instability RP-vector, oriented from the resistance given by abutment-teeth to the pressure given by the absent teeth, shows the area where an additional support is required. In case that in that area no teeth are present, the support can be extended on the nearest teeth, or implants can be set up to take over part of the mechanical load.

After registering the patient in the application, in order to identify the diagram at a later stage, the forms for biomechanical processing of the clinical situation are activated. In the next step, the absent teeth are marked on the dental arch which is displayed on the screen and then the user selects the options for displaying the diagram. These options are:

- display of the appliance;
- display of the RP-vector;
- display of the vector lines;
- display of the RP in millimeters;
- display of dental arch centre of gravity;
- display of the appliance centre of gravity.

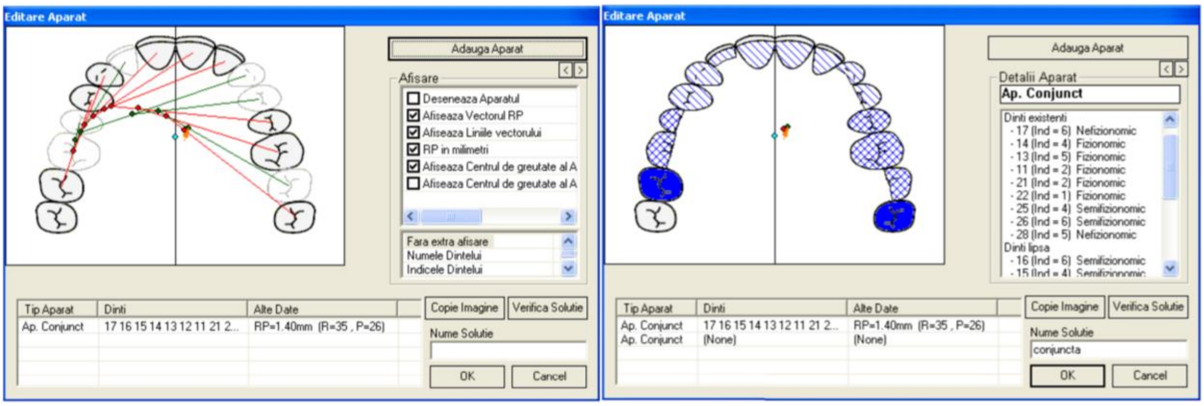


Fig. 80. RP vector drawing and prescription of appliance

This way, depending on the clinical situation and on the requirements, only the RP-vector or the lines that construct the vector can be shown. At the same time, the elements of the prescribed gnato-prosthetic apparatus can be displayed. The software automatically makes the computation according to the polynomial law, comparing the strength to the action force and determining to what degree the prescribed prosthetic construction can rely on the teeth next to the edentulous space only, or the support must be extended.

The features of the prosthetic appliance are gathered automatically in the program window from the dental arch view. The option can be made for one of the existing restorative variants – physiognomic, semi-physiognomic or non-physiognomic.

Once the therapeutic solution is reached, it can be saved, printed or modified.

Conclusions

Our century is defined by the technical and informational revolution. Dentistry is tributary to the developments and research results derived from other fields, with which it apparently has no connection: aeronautical and space industry, automation and robotics, construction industry, informatics, biomaterials, architecture etc.

Informatics finds its place in dental medicine domain in all clinical and technological phases of the therapeutic algorithm and, in addition, in the training of students and future dentists.

In the particular case of dental practice, in order to streamline healthcare, in the last decade, a large number of application software have been designed to create databases containing patients' records, with personal data, health status evolution and performed therapeutic maneuvers. Our software, developed in 2005, was fulfilling the need for a centralized information and management system, supporting the both the administrative and medical activity.

2.3.1.3. Application software for the evaluation of the dento-somato-facial aesthetic balance

Aim of the study

DSF (Dento-Stomato-Facial) Aesthetic Software is an application that focuses on aesthetic evaluation based on the following inter-related directions: body aesthetics, dental-facial aesthetics, dento-gingival aesthetics, dental-dental aesthetic and dental aesthetics.

This paper proposes a new approach of the dento-somato-facial aesthetics by focusing on the following interconnected elements: body aesthetics, dental-facial aesthetics, dento-gingival aesthetics, dental-dental aesthetic and dental aesthetics. At the same time, the paper presents a novel computer application for the assessment of the dento-somato-facial balance. The original contribution of this software is the approach of the aesthetics disequilibrium from the somatic point of view as well as facial and dental point of view, unlike other software that focus only on the facial and dental aspect.

The reason of this enhanced approach resides in a profound knowledge of the stomatognat disequilibrium, each component, including the somatic one, playing an import part in achieving the desired harmony overall.

Material and methods

Computers demonstrate their utility in all the clinic-technological phases of the therapeutic algorithm and also in the dental training of the future practitioners. DSF aesthetic soft is an application that employs different image processing technics and modern data base systems and development platform for a better identification and usage of the dento-facial and somatic aesthetic evaluation criteria (Fig. 83). This application runs on Windows XP, Windows Vista and Windows 7 and for generation reports Microsoft Office (2003, 2007 or 2010) is required. The goal is to process different images and to make measurements, angle calculations, planes drawings which are all specific to aesthetic balance assessment. The application uses Microsoft Access Database.

Fig. 81. DSF Aesthetic Soft splash screen

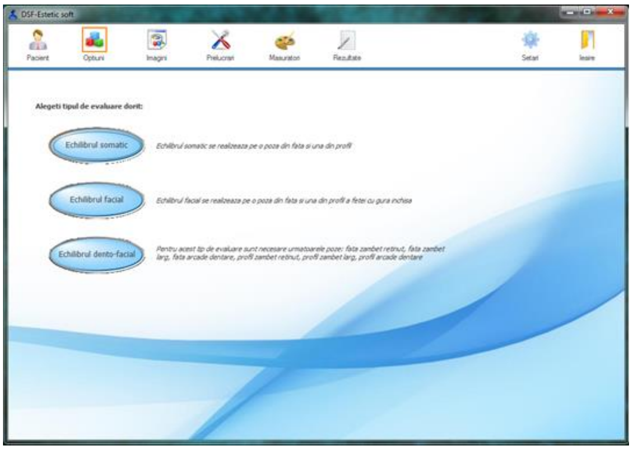


Fig. 82. Evaluation types

Results

The software is based on the following modules:

1. Patient management

Like most of the dental software designed for dental practices, DSF Aesthetic Soft contains a patient management module. It can create, edit, delete, load and save patient data. Patient data are saved in data based which can be used in other platforms or can be imported in other dental applications.

The database is structured on several tables, containing specific data. For patient management, the patient table is used containing information like first name, last name, birth date, address, phone, email, ID etc. Already existing patient data can be loaded and the evaluation process can be continued or restarted by adding new measurements or re-measuring some parameters. New patients can also be created. Already existing patient data can be loaded and the evaluation of the patient can continue by adding new measurements or modifying existing ones. Also, patient data can only be visualized. Using the application new patients can be added (Fig. 85).

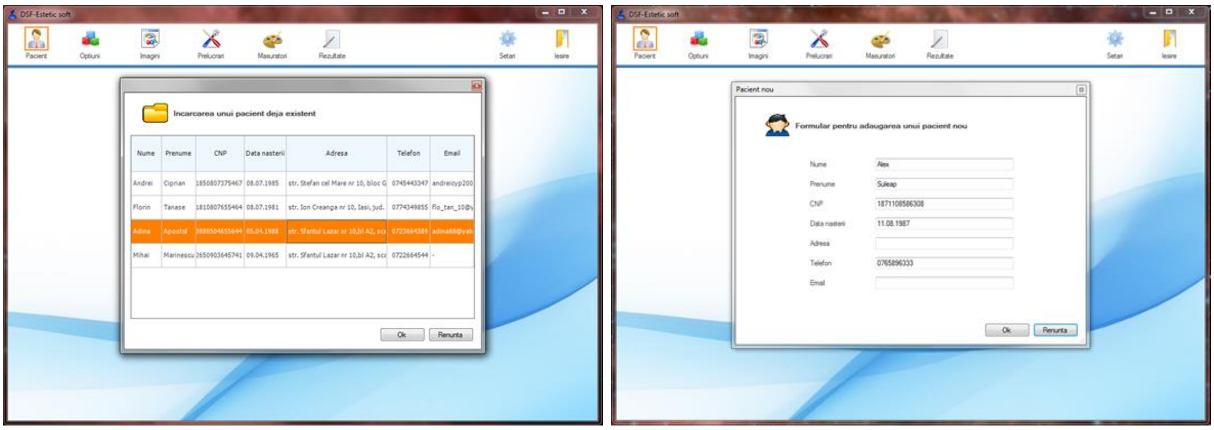


Fig. 83. (a) Patient module function; (b) Loading patient data: (c) Adding new patient

2. Application options

This software focuses on the esthetical evaluation on 3 levels: somatic balance, facial balance and dento-facial balance (Fig. 84).

a. *Somatic balance* - This type of evaluation requires 2 pictures: one from front and one from the side. The pictures include the whole body because measurements of different segments of the skeleton are desired (from the shoulder, waist, elbows, iliac crest, knee etc.).

b. *Facial balance* - For this evaluation 2 pictures are required: picture from the front with closed mouth, one from the side also with the closed moth. The pictures must include only the head of the patient, because the points of the interest are trichion, ophryon, nasion, menton etc.
c. *Dental - facial balance* - For this type of evaluation six pictures are required: front picture with smile, front picture with a wide smile, front picture with evident dental arches, side pictures with smile, side picture with wide smile, side picture with dental arches.

3. Images selection

Patients' images should be grouped in folders as follows: in the application folder one subfolder for each patient should be created. Inside this folder, 3 different folders should be created, one for each evaluation type (somatic, facial, dento-facial). Other images could be created like whole body front picture. The best images can be selected having as criteria the image quality and the visibility of the important elements which are at the base of the evaluation (Fig. 86). The images used and their purpose are stored in the data base. The table pictures contain information like the folder where the picture file is located, picture file name and usage of the picture (if it is a front whole-body picture or a picture of the dental arches). The user must select the source folder which contains the desired images and then select the images that will be used for the evaluations.

4. Standard image processing

As in the case of image processing applications standard image processing is required also in this software. One of the most important features is image rotation which is needed for setting the subject in vertical position. The picture can be rotated with an angle between -10 to 10 degrees. This is an important step for standardizing the image which will ensure more precise measurements. The "zoom" feature is useful for visually amplifying some elements contained in the picture.

Other functions like brightness contrast have the role of enhancing the quality of the picture which will help the measurement process. The most important role of these image processing functions is to create high quality image of the subject. However, a picture that does not contain the necessary information cannot be greatly improved by the image processing technics. This is way the image acquisition is very important in the first place. Proper lighting and a good resolution are recommended. If the acquired image is of poor quality, then retaking that picture might be the best option, instead of processing it.

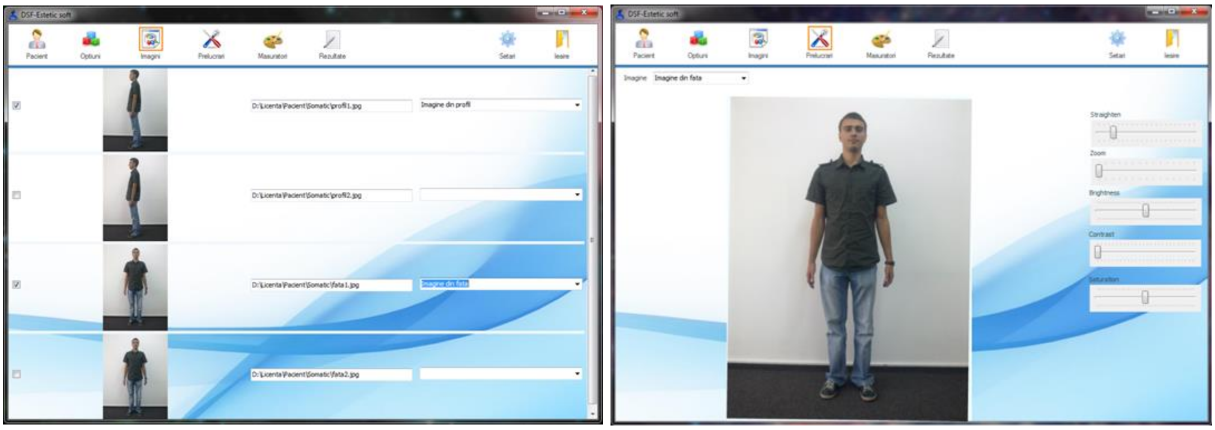


Fig. 84. Image selection. Image processing

5. Measurements

This is the most important step for the evaluation process. At this stage the user has already selected a patient and the type of the desired evaluation, has important the necessary images and performed the necessary image processing. If at this point the images have not the necessary quality for starting the images process, then all the above steps have to be repeated. In this module the user will define certain guide points on the body which will help in measuring distances, ratios, angles etc.

Every guide point is saved to the database, in the table points using the XY coordinates which will define the point location in 2-dimensional space. These points define different elements like left shoulder, right knee etc. These points that the user has to define are grouped in several section based on the desired evaluation type. However, for each picture some reference points have to be defined. These pints are not used in the actual computation but are essential for the evaluation. Some of these points define the marker line.

The marker line is the line for which the real size is known. This is necessary for calculating the ratio between the image dimensions and the real-world dimensions. The marker line could be any element not necessarily related to the subject body. It could be also an object visible in the image.

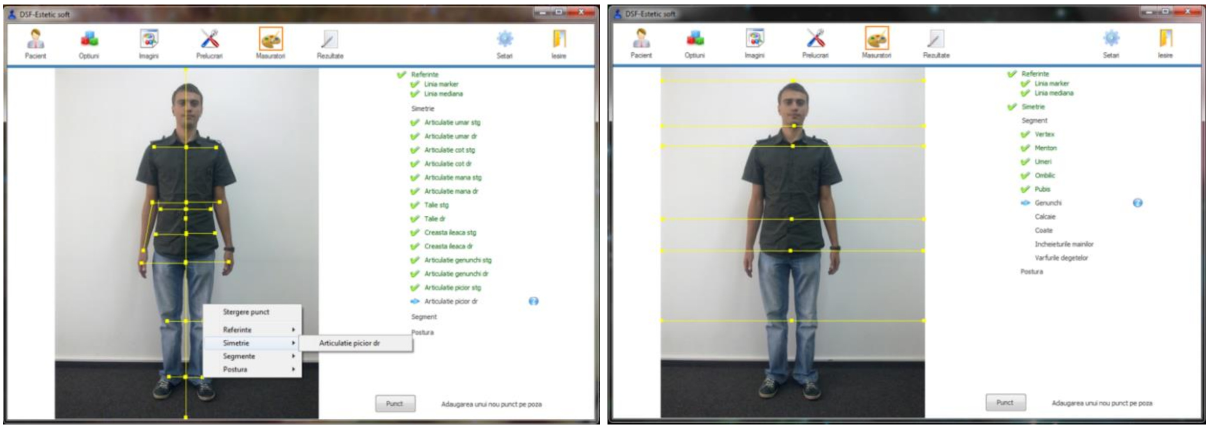


Fig. 85. (a) Defining points. (b) Defining segments

In the image below, we used the forearm which is parallel to the image plane. In the above example we used somatic evaluation, based on the front image. The symmetry based on the median line is analyzed. This means the reference is the median plane. For this the user has to select one point and then draw the vertical line that runs through it. Next all the points from the displayed list have to be defined: left shoulder, right shoulder, left elbow etc. If one point is skipped some evaluation will not be possible. In the example bellow the display points have to be defined for evaluating the segments: vertex, menton, shoulder etc. For each point a horizontal line is drown dividing the subject's body into several sections. For defining a point, reference image can also be used. Other examples for defining points for facial evaluation front and side images are showed in Fig. 87.

A necessary stage in diagnosis is the analyses of cephalogram. The specialist can draw the necessary planes and angles in order to establish the type of the dental facial imbalance (Fig. 88).

6. Reporting

Once the points, segments and planes of interest, the software automatically performs the data processing. This consists of comparison between similar sections, distance calculation between different points and reference planes, ratio calculation and comparisons with references values. In the images above, symmetries based on the median line are evaluated for the full body as well as for face and dental arches. Similarities and ratios between the segments are also evaluated.

On user request, the software will display all the resulting values or only those who lie outside the normal range. The final reports can be shown over imposed on the patient's image pointing out the deviating segments or on a standard image from the own library. These standard images can also be accessed through the help menu.

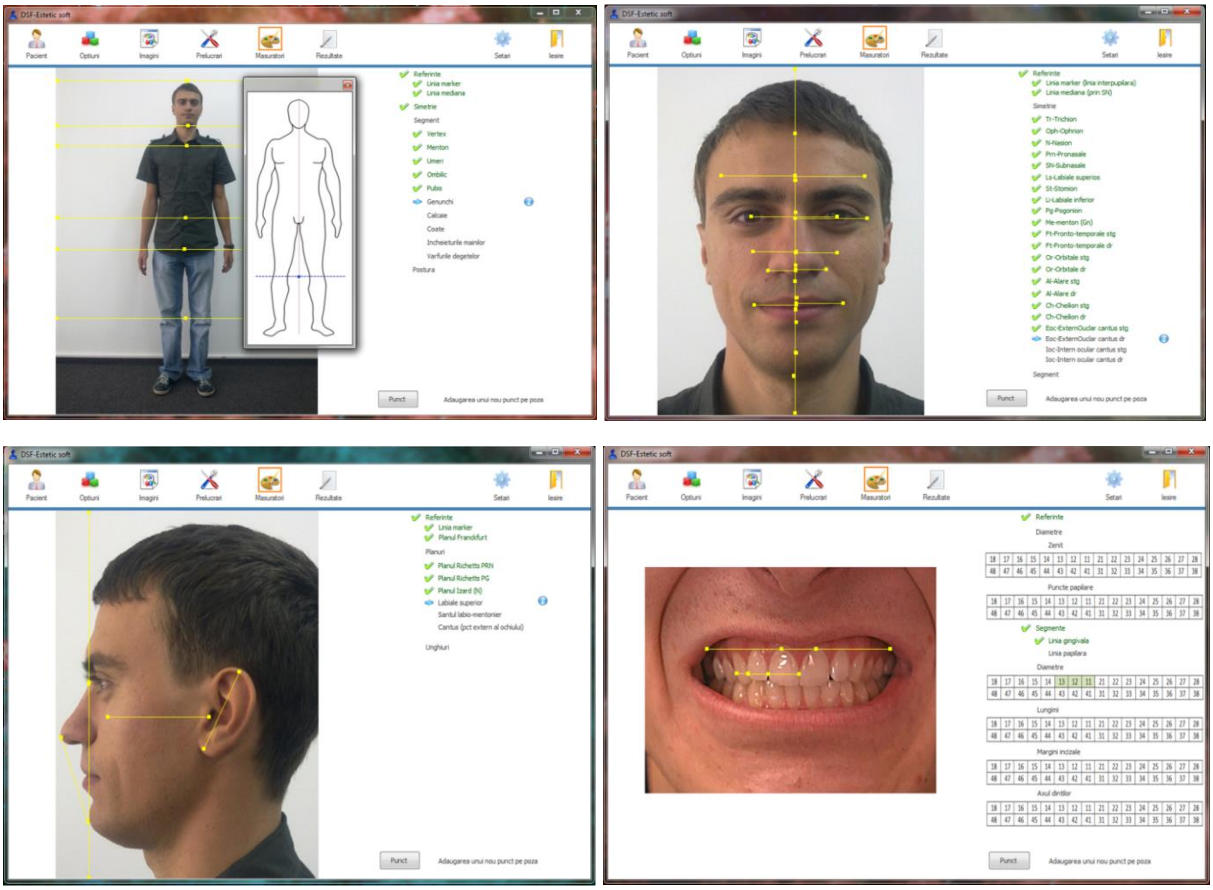


Fig. 86. (a) Reference image. (b) Reference points front image. (c) Reference points side image. (d) Reference points dental image

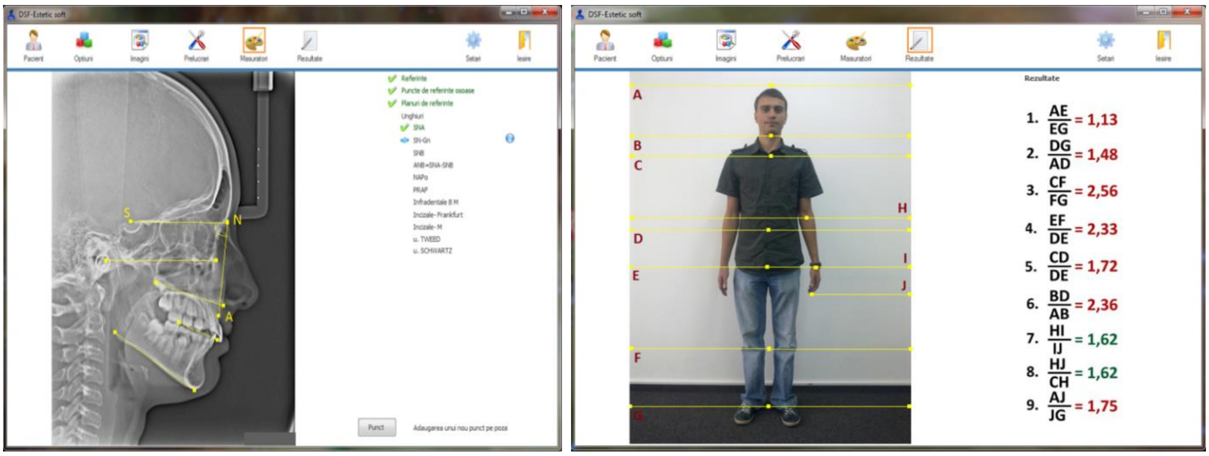


Fig. 87. (a) X-ray measurements. (b) Full body ratio calculation

Even though the application software reveals the abnormal geometrical relations, guiding the specialist towards diagnosis, the final interpretation belongs to the medical expert who will establish the final diagnosis. This is achieved by correlating data from the computer application with information obtained through clinical and paraclinical evaluation which are obligatory in a complex and complete approach of the case.

Discussions

It is more and more obvious that to be a high standard medical specialist requires not only good training in theoretical al practical aspects of a specific medical area but much more. "No doubt, Pius Servien used to say, you have to be born for science and for art as well" [343]. It requires besides of vast medical culture, the knowledge of ethical and moral principles in general, and also sound intellectual qualities. Beyond that the specialist has to nurture his or her aesthetic sensibility good taste and artistic refinement. How the medical specialist could otherwise perceive and understand the abnormal situations, the disease which affects the beauty and harmony of a healthy human body? Without all these qualities the personality of a specialist appears cold and sterile, transforming him / her into a repository of scientific knowledge.

Today, due to the evolution and development of numerous technics and aesthetic materials, dentistry is considered, more than ever, an art. As in most art forms, the final results of the dental technics have to be also very pleasant. However, unlike other art forms, the aesthetics cannot be only the contribution of the artist. The concept of the dental aesthetics is subject of numerous variations which has to do with the personal interpretation and individual perception. Although the final result is controlled by the dental practitioner, the patient has to directly contribute to the decision making process.

Conclusions

1. This paper proposes the approach of the dento-somato-aesthetics based on the following the interrelated directions: body aesthetics, facial aesthetics, dento-facial aesthetics, dento-gingival aesthetics, dento-dental aesthetics and dental aesthetics.
2. We present a computer application for evaluating dento-somato-facial balance. The original contribution of this application is the software concept that proposes the approach of aesthetic imbalances not only from dental and facial point of view, but also from somatic point of view.
3. The motivation of this concept resides in a profound knowledge of the stomathognat system imbalances. Each component, including the somatic one, plays a very important role in the overall harmony.
4. The main characteristic of this paper is the interdisciplinary way of thinking by correlating anthropometric and orthopedic data, different dental specialties and computer processing, resulting in a software with immediate clinical and educational applicability.

2.3.2. VIRTUAL PATIENT SOFTWARE

2.3.2.1. State of the art

Having the results of Bloom's research [344] as a starting point, Anderson & Krathwohl [345] propose a revised classification of learning related cognitive processes: (a) knowledge retrieval, (b) comprehension, (c) application, (d) analysis, (e) evaluation, (f) creation. Bloom established that most student assessment methods were only addressing the first level, knowledge retrieval. However, a complete learning process must build abilities on all six levels. Computer Assisted Learning (CAL) is a valuable tool that responds to these requirements preparing students for problems they will encounter in real-life by using complex simulations of realistic situations.

In Romania, according to the Romanian ***College*** of Physicians, the healthcare sector has a deficit of 40% in the number of healthcare professionals. At the same time, it is affected by a chronic lack of funds and struggles to cope with the large number of patients that request medical services. To complete the picture, the academic domain gradually lost its attractiveness mainly because of the low wages, high demands and precarious working conditions. Under the circumstances the educational process is also impaired. An enhanced individual study could at least partly compensate these shortcomings by using new technology supported learning methods. Promoting individual study or learning in small groups improves performance of future medical professionals which is beneficial to the social and to the economic environment.

Medical education has some particularities: rich scientific terminology, large volumes of information in form of static images, audio and video materials, the importance of accumulated experience in previous clinical challenges, use of human subjects in the training process, etc. As stated in [346], "traditionally, medical education had as its foundation a combination of didactic instruction in the classroom and integrated, hands-on *Socratic Method* learning in the clinical setting". This is why Case-Based Learning (CBL) and Problem-Based Learning (PBL) are learning paradigms that gain popularity by involving the trainee in complex and interesting activities that stimulate the learning process. They encourage collaboration on solving various problems, decision taking and research. Studies like [347], [348] and [349] show that medical staff that did PBL training stages had increased abilities in solving clinical problems.

Computer Assisted Learning as part of the e-Learning is a training method centered on using computer software. By interacting with the application, the trainee engages a series of activities that support the learning process. This is achieved by helping the trainee to understand the connections between various elements and by stimulating the memorization for a long duration. Furthermore, due to a computerized environment, the level of interactivity is much higher compared to the classical learning paradigm based on student-professor interaction. Text, images, audio and video sequences represent multiple channels through which information is passed to the trainee.

One of the most modern and efficient computer-assisted learning methods uses the *virtual patient* concept (VP). This concept encompasses the interactive computer simulations used in medical education which are focused on simulating the clinical stages: history taking, physical examination, ordering laboratory tests, establishing the diagnostic, prescribing the therapy, getting the feedback. Creating VPs requires scientific excellence, modern technologies and is based on the *Game Based Learning* concept. VP applications allow trainees to exert the role of a medical professional and support the development of clinical and decisional abilities [350]. This kind of software is gaining popularity as it facilitates the learning process through an increased variability of the clinical cases accessible to the trainee but also by offering a controlled and safe environment which can boost the confidence of the trainee in its own clinical abilities [351].

There is quite a while since computer technology made its way into medicine but it is only in the last decade that it went beyond medical imaging and started to support various medical activities that used to be an exclusive responsibility of the human medical professional. A clear sign of this progress is that its concepts are now popular and do not require further explanation. Along with CAD/CAM, terms as clinical simulation, 3D-modelling, virtual patient, e-Learning, simulated patients etc. are nowadays usual concepts that describe areas in which medicine interfaces with the new technologies.

One of the directions in which this collaboration has rapidly expanded is the medical education. This development is due to a series of particularities of this field like: rich terminology, use of large volumes of information in form of static images, video and audio material, complex clinical situations that require the combining information from several sources, use of human subjects in the training process, etc.

Dental material selection is the key process in the patient treatment plan. Considering the high standards of nowadays dentistry and, unfortunately, the limited possibilities in university clinics, the young doctors might find themselves in front of an overwhelming dilemma concerning material selection, appropriate technique and technology.

The traditional medical education is based on a combination of didactic information transfer in the classroom and hands-on learning in a clinical environment (the Socratic Method [352]. Therefore, paradigms as Case-Based Learning (CBL) and Problem-Based Learning (PBL) are at the core of clinical training. The real challenge with this approach is to confront the trainee with a comprehensive array of clinical problems and situations that can appear in real-world scenarios. At the same time the environment in which these training activities take place must be attractive and complex enough in order to capture attention and to stimulate the learning process. Connected activities as cooperation on problem solving, documentation and decision making are strongly encouraged. Studies have shown that medical professionals that underwent a PBL training have increased abilities to solve clinical problems [347, 348]. The Computer Assisted Learning as part of the e-Learning domain is a learning method that makes use of specialized computer applications.

David Hadden, TheraSim founder, referring to the necessity and justness of simulation introduction in medical education [353], made a troubling comparison between the percentage of plane crash victims and that of the health care system, when the human factor was decisive. In similar flight situations, the difference between a happy ending and a catastrophe was determined by the type of training that the pilots received. In the first situation, the pilot was trained on simulator, in the other case he received only theoretical training. Among other security measures, the mandatory flight simulator training makes the plane the safest means of transportation, while the health care system continues to make many victims despite its mission. One of the major causes is the inadequate training of medical staff, as the article points out. Therefore, adopting simulation training in medical education seems the logical and necessary way to go.

In the e-learning medical education, one field of particular interest is that of Virtual Patients. It emerged in the past 10 years as a novel technology supported medical training method and encompasses several approaches:

- simulated patients – patients recreated by other persons (actors) or computer generated characters with various level of details;
- real patients represented by their electronic medical file (e-Patient);
- computer simulated clinical cases – users must perform different activities and solve problems they encounter in the simulated setting.

Virtual patients as computer simulated cases have gained in popularity due to some important characteristics:

- creates a simulated clinical setting and offers of an increased level of interactivity compared to the traditional learning method;
- safe to use in all levels of expertise and all simulated problems, because no human patients are involved;
- flexibility in designing the clinical scenarios;
- use of multi-media content in describing the clinical case;
- possibility of reviewing the decision-making process;
- use in learning and evaluation activities;
- accessibility from any location and at any time;
- low implementation and operation costs, etc.

At the international level, especially in the US [354-358], but also in Europe – Germany [359, 360], Sweden [361], England [362-365], there is a high degree of acceptance among the prestigious universities for virtual patient programs, contributing to their academic excellence.

Virtual-patient (VP) software is an innovative educational tool which provides a safe environment in which students and interns can acquire clinical skills before engaging in real patient cases. Virtual patients allow the study of different scenarios regardless of the teaching staff availability, student location or, more important in dentistry, accessibility to patient, dental materials and different technologies.

The development of computers and especially the spreading of portable devices have made education inseparable from these technological advances. PowerPoint presentations have replaced explanations on the black board, note-taking is now readily available on laptops, course materials are accessible on university platforms and all additional information can be found or obtained on the Internet. In this context of increasingly rapid virtualization, sharing and propagation of data, it is necessary to update and rethink the tools of medical training. Virtual libraries are now well developed, scientific journals have a full digital version and there are explanatory videos in many disciplines. In this continuity, we are now considering the development of simulations in the field of health education, from simple scenarios in the form of text, to the device of augmented reality.

The support of information has greatly evolved in the course of human history with significant events since the first oral transmissions, starting with the appearance of writing, from hieroglyphs to alphabet. Secondly, the invention of the printing press was a revolution and made it possible to disseminate information widely and at lower cost. It is towards the end of the XIXth century that the information is detached from the physical support with the telephone (1876), the radio (1901) and the television (1926). Then in 1970 the first computers and the first computer networks appeared, and finally in 1992 CERN introduced the WWW (world wide web) servers which opened the doors to the era we know today [366]. The first "machine to teach" is surely the *Drum Tutor* of the American psychologist Sydney Pressey. It is a sequential machine that requires to go through a chain of operations to obtain the information [367]. Today, mannequins or computers are used to develop medical simulations.

Simulation pedagogy in dental schools has undergone a significant evolution over the last thirty years. Although the use of virtual patients is relatively new in dental education, the use of simulated patients, in combination with laboratory data, for diagnosis and treatment plan, was used as early as 1990. In 2000, the European Commission validates the action plan "E-learning, thinking about the education of tomorrow". It is part of the eEurope Global Action Plan which "aims to enable Europe to exploit its strengths and overcome the obstacles to the integration and increased use of digital technologies" [368].

The Haute Autorité de Santé defines health simulation as "the use of a material (such as a manikin or a procedural simulator), virtual reality or a standardized patient to reproduce situations or environments of care, in the purpose of teaching diagnostic and therapeutic procedures and of repeating processes, medical concepts or decision-making by a health professional or a team of professionals" [369].

Virtual patient simulation (PV) makes it possible to present, using scenarios, realistic clinical cases in which the learner seeks to obtain all the information necessary to establish a diagnosis and to propose a therapeutic management [370]. Emphasis is placed more on the skills of thinking, logic and application of knowledge than on purely practical skills. The Virtual Patients simulations are a mandatory learning instrument especially in some university clinics with limited possibilities and resources. They can constitute a bridge through the real clinical situations, familiarizing the future dentists with different situations, techniques and technologies otherwise difficult to access.

The development and use of educational software in general, virtual patient software, in particular, interests more and more universities that come together and work together, thanks to the Internet in order to exploit the best tools and share their progress [371-373]. A wide variety of commercial and open-source VP systems, such as vpSim, Web-SP, MedSims, CASUS, CAMPUS, OpenTUSK, OpenLabyrinth, or i-Human are available and applied in health care education [374, 375].

Information technologies have a growing role in medical education, especially in the last decade, bringing several undeniable advantages. New concepts such as e-Learning, virtual patient and active learning are increasingly present in the projects of renowned universities, as well as in the university curriculum. Virtual patients allow the study of clinical scenarios regardless of the availability of a teacher, the place where the student is or, more importantly, the access to a real patient. The limited possibilities regarding access to the necessary materials, equipment and expertise existing in a certain area open a way of affirmation for training platforms based on virtual patients [374]. Studies show that these innovative methods enjoy a high degree of acceptance among both students and teachers and that they can complement the traditional methods of training so that together they will lead to improved results of the teaching act [376].

The term virtual patient refers to cases where the patient is not "real" and includes [377]:

1. Simulations of computerized patients from a computer or server - these are used for learning by students or by young doctors using an algorithmic approach that leads to diagnosis and to good patient management.
2. Actors who simulate and act in accordance with the symptoms of a specific disease and provide accurate responses to the student.
3. Three-dimensional graphical simulations that evaluate manual skills, for example in surgical gestures.

G. Alinier gives us a scale of six levels of simulation depending on the complexity and the interaction possible with the learner and according to the characteristics of the simulators [378]:

- Level 0: written simulations (clinical cases);
- Level 1: three-dimensional anatomical models;
- Level 2: computer simulation, CD-ROM, video clinical cases, virtual reality
- Level 3: standardized patient played by actors
- Level 4: intermediate fidelity patient simulators
- Level 5: high-fidelity interactive patient simulators

Although in education, virtual patients have been used for many years, there is a certain level of confusion when trying to define the term of virtual patient [379]. A definition by the American Association of Medical Colleges (AAMC) describes virtual patients as “a specific type of computer-based program that simulates real-life clinical scenarios; learners emulate the roles of health care providers to obtain a history, conduct a physical exam, and make diagnostic and therapeutic decisions” [380].

	Most relevant personal scientific contributions in this field (the highlighted papers are presented in extenso in the next chapters):
ISI	1. Doloca A, Ţănculescu O, Ciongradi I, Trandafir L, Stoleriu S, Ifteni G. *Comparative Study of Virtual Patient Applications*. Proceedings of the Romanian Academy, Series A 2015;16(3):466-473. FI = 1,658/2014 http://www.acad.ro/sectii2002/proceedings/doc2015-3/10Doloca.pdf 2. Doloca A, Ţănculescu O, Trandafir L, Ciongradi I, Stoleriu S, Vieriu R, Ifteni G. *Dental Materials and Their Selection – Virtual Patient (VP) Software from a Student Perspective*. Materiale Plastice 2016; 53(3):370-374

	http://www.revmaterialeplastice.ro/pdf/DOLOCA%20A%203%2016.pdf
IDB	3. Mille R, Tanculescu O, Vieriu RM, Surlari Z, Luca E, Ciocan-Pendefunda AA, Checherita LE, Aungurencei O, Virvescu D, Doloca A. *Use of the openlabyrinth software for authoring virtual patients in dental medicine II*. Romanian Journal of Oral Rehabilitation, 2019, 11(4):249-257 http://www.rjor.ro/use-of-the-openlabyrinth-software-for-authoring-virtual-patients-in-dental-medicine-ii/ 4. Mille R., Tanculescu O., Andronache M., Ifteni G., Apostu A., Ioanid N., Virvescu D., Doloca A. *Use of the openlabyrinth software for authoring virtual patients in dental medicine* I. Romanian Journal of Oral Rehabilitation, 2019, 11(2):62-70 http://www.rjor.ro/use-of-the-openlabyrinth-software-for-authoring-virtual-patients-in-dental-medicine-i/

2.3.2.2. Comparative study of virtual patient applications

Aim of the study

This paper focuses on getting an overview picture of the most popular virtual patient software currently available, through comparative analysis. It is by no means the purpose of this paper to establish a ranking of these software products, but to determine the current state and the direction of development in this field. To this end the following specific issues will be approached:

- establish the criteria for comparative analysis;
- select virtual patient products to be included in the study;
- acquire information according to the proposed criteria;
- analyze acquired information by pointing out common features and differences;
- comment on the results.

Materials and method

a. Assessment criteria

For the comparative analysis, three categories of criteria were considered: target, functional and technical.

The first category looks at the current users of various virtual patient software and at the specific domain that the software targets (medicine, pharmacy, dental medicine, other).

The second category concentrates on the application usage and features that are important from the user perspective, both author and trainee, while the third category encompasses technical aspects of the software product. Based on the mentioned categories, the following criteria were taken into account.

b. Virtual patient software selection

We conducted the research using Internet sources and scientific papers to determine the virtual patient software systems to be considered in this study. The MedBiquitous Consortium develops information technology standards for the healthcare domain. The list of the MedBiquitous Virtual Patient Standard implementers can be found in [371]. Besides these, other virtual patient systems were also taken into account considering their user base and their visibility in the media. Adoption by universities and inclusion in their healthcare curricula was also a considered aspect. The eViP, a European effort to build a database of 320 virtual patients also mentions the most important platforms currently in use.

Based on the assessment criteria (Table 65), an analysis of the common traits and differences of the virtual patient platforms will be performed. Most important characteristics will be pointed out and the trend in the development and usage scenarios of these platforms will be discussed.

Table 65. Criteria for virtual patient platform assessment

Target	Functional criteria	Technical criteria
• **current users** • **target audience** • **domain**	• structure • multimedia content • import/export capability • metrics available • VPs deliverable on mobile devices	• platform • operating system (client and server) • programming language • license type

Results

1. **vpSim** is a software product which was developed starting with 2007 by the *Laboratory for Educational Technology, University of Pittsburgh School of Medicine* for the computer simulation of clinical cases. **DecisionSim** is a commercial version based on vpSim, built by the Decision Simulation company beginning with 2010 [350]. In these applications, the student plays the role of a medical professional that interacts with a virtual patient through the computer screen. The actions of the medical professional are typically the following: patient interview, physical examination, prescribing tests, establishing the diagnosis and establishing the therapeutic algorithm.

2. **MedSims** is a software platform initially created by TheraSim and currently developed by WebMD with the purpose of improving the educational process using virtual patients. MedSims presents realistic clinical scenarios that can be approached by the trainee in a risk-free virtual environment. The platform incorporates the National Committee for Quality Assurance’s (NCQA) formula for improvement: Measure, Analyze, Improve, and Repeat. Among novel features, the artificial intelligence simulates more than one million clinical decisions. Free CME resources including virtual patients for various medical specialties are available at [381].

3. **Web-SP** is an interactive virtual patient simulator with a web-based user interface that offers also an authoring tool. The software system was developed by the Karolinska Institute and offers the traditional functionality that is expected from a virtual patient simulation tool: patient history, clinical examination, laboratory tests, diagnostic, therapy, feedback and bibliographical references [382]. Web-SP is implemented in healthcare departments of more than ten universities around the world. Latest version includes features that increase the level of interactivity: free text search through medical history of the patient, improved physical examination, improved feedback.

4. The **CAMPUS** software was created by the University of Heidelberg Germany as an interactive case-based multimedia learning system. Real life clinical scenarios are simulated covering all the steps: patient history, diagnosis and therapy. The system provides feedback for each decision of the user. CAMPUS offers several work scenarios: authoring tool, linear case presentations, knowledge evaluation module [359]. The linear card-based structure is well suited to preclinical and CME. When authoring a virtual patient, a pre-built template can be used. Interactive images as a useful means of knowledge transfer can be produced even by unexperienced users and can be included in the developed virtual patients.

5. **OpenLabyrinth** is an open-source system for authoring and playing virtual-patients [375]. It is developed and maintained by a consortium of universities: University of Calgary, Queens University, Northern Ontario School of Medicine, Aristotle University Thessaloniki, St. George’s University London and Karolinska Institute. The software can be installed on servers

running on Linux or Windows Server operating system and requires a web server with Apache, a MySQL database engine and PHP. LAMP or WAMP preconfigured servers allow a fast installation of all these required components. OpenLabyrinth can be used as an assessment tool due to its detailed metrics which are built into the server. The virtual patients can contain any type of media and can be used for both teaching and assessment activities. Also, instead of running the virtual patient cases in OpenLabyrinth these can be accessed by communicating with the web services that OpenLabyrinth provides. In this way a custom user interface can be developed that works with the OpenLabyrinth engine in the backstage. The OpenLabyrinth project is actively developed, currently version 3.2 (12.08.2014) being the latest release. A demo is available at [383].

Table 66. Targets of virtual patient platforms

No.	Software	Users	Target audience	Domain
1	vpSim	UK: St Georges Univ. of London, Warwick University, University of the West. US: Northwestern University, Cleveland Clinic, University of Pittsburgh	all education levels and content domains but optimized for healthcare	medicine, pharmacy, dentistry
2	MedSims	US universities and medical institutions	students and teaching staff from medical fields	medicine and pharmacy
3	Web-SP	Universities and medical institutions around the world, e.g. Stanford [384]	undergraduate students, postgraduate students, CME	medicine, dentistry, pharmacy
4	CAMPUS	Universities from Germany, Netherlands, Bosnia and Herzegovina, Romania	all	all medical fields
5	Open Labyrinth	St George's, University of London [385], “Iuliu Hatieganu” U.M.Ph. Cluj Napoca, Northern Ontario School of Medicine, Aristotle University Thessaloniki, University of Calgary [386], University of Edinburgh [387]	undergraduate students, postgraduate students, CME	all medical fields
6	OpenTUSK	Medical, dental and veterinary schools at Tufts University and other users in the US, Africa and India [388]	undergraduate students, postgraduate students, CME, schools	medicine, dentistry, veterinary medicine
7	CASUS	Med-U [389], NetWorm [390], other universities and virtual universities in Europe (medical schools, dental schools, veterinary schools and CME)	undergraduate students, postgraduate students, CME, law schools	medicine, dentistry, veterinary medicine

6. **OpenTUSK** is a platform built on the foundation of a content management system designed to manage several aspects of teaching in health sciences schools: curriculum, courses, content, clinical teaching, personalized knowledge, student data and faculty enrolment. The clinical teaching features a virtual patient builder which can be used to create interactive exercises for presenting clinical cases. The usual activities are simulated: performing physical examination, ordering tests, creating differential diagnostics, etc. [388]

7. **CASUS** is a case-based, multimedia learning and authoring system developed by Instruct AG, Germany based on the linear or string of pearls structure. The platform features several modules: Authoring System, Learning System, Course Manager, ExamTool, Evaluations and mLearning.

The CASUS system can be easily integrated with popular learning management systems (Moodle, ILIAS, CLIX). Demonstrative cases can be found in [391]. Until 2010 more than 1000 cases have been created and deployed to various educational institutions [392].

Information according to the criteria in Table 66, acquired for all virtual patient platforms, is presented comparatively in Tables 67, 68 and 69.

Table 67. Functional characteristics of virtual patient platforms

No.	Software	Structure	Multimedia content	Import/ export in MedBiq std. format	Metrics	Mobile
1	vpSim	linear and branched	yes	yes	yes	yes
2	MedSims	linear and branched	yes	no	yes, using complex metrics for assessment	yes
3	Web-SP	linear	yes	yes	yes, through exam module	yes
4	CAMPUS	linear	yes	yes	yes	yes
5	Open Labyrinth	linear and branched	yes	yes	yes	yes
6	OpenTUSK	linear and branched	yes	yes	no	yes
7	CASUS	linear	yes	yes	yes, with evaluation modules	yes

Table 68. Technical characteristics of virtual patient platforms

No.	Software	Platform	Server OS	Programming language	License type
1	vpSim	web application	Windows Server	ASP.NET, Flash	annual license
2	MedSims	web application	Linux	PHP	limited access with user account
3	Web-SP	web application	Unix/Linux/Win/ Mac OS X	Java	limited access with user account
4	CAMPUS	web application	not available	not available	commercial or free for educational partners
5	Open Labyrinth	web application	Windows, Linux, MacOS (LAMP, WAMP)	PHP	open source (GNU General Public License)
6	OpenTUSK	web application	Linux	Perl	Educational Community License, Version 2.0 (ECL-2.0)
7	CASUS	web application	not available	not available	license fee issued by Instruct AG

Discussions

All software platforms included in this study are state of the art tools capable of revolutionizing medical education. The advances in computer technology, both in software and hardware and the ubiquity of Internet access create a strong foundation for delivering new learning technologies closer to the users. As Table 68 shows, all Virtual Patient platforms share an important feature: they have been developed as web applications. Local, offline content distribution on CD-ROM or DVD-ROM is a thing of the past. This means that an Internet connection is required but at the same time a number of important advantages emerge:

- widespread availability eliminating the need of being present in a classroom;
- compatibility with mobile devices (see Table 67);
- no installation required on the client side;
- simplified update, upgrade or patching procedures as these affect only the centralized server-based installation.

The software technologies used to build these software products are currently the most popular in the field. ASP.NET was used for server-side programming in the Windows Server based platform vpSim. Some platforms, on the other hand, are Linux based, which confirms the trend in the field of enterprise applications. Linux is now leading the server market due to its performance and security characteristics, and this is also the reason it was selected for the rest of the analyzed platforms. Having Linux as the operating system, programming languages like PHP, Java and Perl have been employed being popular for their stability and performance.

Looking at the current user base it becomes clear that this type of new learning technologies has gained acceptance in prestigious universities around the world. They are used as a way of enriching the traditional learning methods and are included in the faculty curricula. The adoption process is not a simple task and requires a sustained effort for interfacing with the classical teaching paradigms and for constantly enhancing the virtual patient collection both in number and in subject coverage. In terms of targeted audience, the analysed platforms can cover all educational levels: undergraduate students, postgraduate students, continuing medical education (CME). Some platforms have been successfully applied to other fields like veterinary medicine or law school (see CASUS).

Regarding the structure of the underlying clinical case, some platforms can author and play only linear virtual patient systems (Web-SP, CAMPUS, and CASUS) while other support both linear and branched models (OpenLabyrinth, vpSim, MedSims and OpenTUSK). [392] states that linear models are easier to implement and to understand which accounts for their spread in the virtual patient community. However only branched systems can allow the trainee to get feedback about the consequences of their decisions in a realistic way [393].

Multimedia content capabilities are present in all platforms as they are a key feature in modern e-learning platforms. Presenting information on multiple channels to the trainee not only stimulates interest in interacting with the software but also improves the learning process itself. Students that have undergone learning stages where multimedia content was involved achieved better performance later and had a greater satisfaction in learning [394, 395]. The analyzed platforms can use a variety of content types: various document types, static images, audio sequences, video files and even YouTube content (e.g. OpenLabyrinth).

Due to the fact that creating virtual patients is a laborious and costly process, sharing them becomes an important issue that contributes to the number of virtual patients available to users. The MedBiquitous initiative set out to create standards that will enable the exchange of virtual patients across systems and institutions. Currently most of the platforms (see Table 67) implement the MedBiquitous virtual patient standards.

Counters are useful features in assessing the quality of the learning process. Education metrics standards [396] create a common platform for exchanging virtual patients as assessment tools. Except OpenTUSK for which we couldn’t find any reference relating to metrics, all other analyzed platforms contain counter functionality either built-in or as a part of the assessment module. In advanced metrics modules, counters can be work together with rules that specify various actions if the counter value meets satisfied some criterion [397].

Concerning the operating systems and the software technologies used for development, two categories have been recorded. For the platform targeting the Windows Server, the ASP.NET language has been employed for the server-side programming and AJAX, CSS, HTML and jQuery for the client-side development. On the other side most virtual patient platforms, as shown in Table 68, are Linux based. This is justified by its performance and security characteristics which drives the increasing popularity of this operating system in enterprise applications. The programming languages were in this case: Java, PHP and Perl. These facts show that developers are considering the current trend towards mobile applications deliverable on a wide range of devices and preferred by many young people. The same reason switched the decision to web applications that are cross-platform, involve a very thin client, namely any web-browser and centralize the core functionality on a server, thereby greatly simplifying management.

An important aspect when planning the implementation of such a platform, especially when the university or institution in question does not have the necessary finances at its disposal, is the licensing type. Two of the seven popular platforms presented in this paper, OpenLabyrinth and OpenTUSK, have been licensed as open source software which grants free usage and opens the code to community contributions [375]. Both are actively developed, and new versions are published periodically. The fact that they are open source does not imply a short list of features or lack of reliability. On the contrary these two products are very rich in functionality and the active developer community behind them is a guarantee for reliability and constant maintenance. They are already implemented in prestigious universities and in production for several years.

Commercial software brings the advantage of carefully designed user interface and increased user friendliness. Licenses are available for universities or for institutions that are active in the healthcare sector.

Conclusions

Virtual patient software platforms are becoming increasingly popular as non-conventional teaching tools especially when it comes to teaching clinical reasoning. These new methods increase the effectiveness of learning by offering a simulated environment which closely resembles real situations. This can be accomplished by creating an immersive effect using multimedia content and narrative scenarios. Nevertheless, the new virtual patient paradigm cannot replace traditional teaching, as human interaction is still an important aspect of the learning process and cannot be yet simulated to an acceptable degree.

In healthcare institutions where the budget does not allow the purchase of a virtual patient platform, open-source alternatives are available. Installation of these platforms is not straightforward but can be accomplished by an IT department and does not require costly hardware investments. In this way new learning technologies can be implemented in underdeveloped countries contributing to the advance of the healthcare domain in those countries.

Considering that users who interact with virtual patient software are not IT specialists, the analyzed platforms have made good progress in providing a simple to use and intuitive interface. However, we consider that improvements are still necessary, especially when the creation of complex structures is targeted. This could be achieved by offering advanced templates that could simplify the creation of this type of cases.

Looking at known examples of virtual patient platform implementations the large majority of them are situated in the medical education area. However, due to its graph structure and the multimedia content, many more fields could benefit from this technology, especially where decisions are a key factor of the specific activities.

2.3.2.3. Virtual patient (VP) software from a student perspective

Aim of the study

The aim of the study was to assess the qualitative general impact of VPs on dentistry students and the qualitative impact of two virtual clinical cases in particular, focusing on the selection of dental materials and the suitable technology.

Materials and method

This research is targeted on a specific aspect of dental training of the 3rd year students at the “Grigore T. Popa” University of Medicine and Pharmacy in Iași – improvement of student ability in selecting the appropriate dental materials in particular clinical cases. The material selection process and the restoration type are generally based on the following criteria: lesion type, extension of the lesion, the tooth/edentulism visibility, tooth volume, tooth vitality and social-economic status of the patient.

A group of 73 students participated in all stages of the study. Their participation took place at the end of the 3rd year of study, was anonymous and not constrained in any way.

In the first phase, using the Google Forms web application, two on-line questionnaires were set up: an initial one (Questionnaire A) to record student opinions related to previous use of VP platforms, type of VPs, software application, expected benefits from VP training. The opinions were collected prior to completing the VP session. During the second phase, two virtual patients with dental lesions and edentulism were designed as simulated algorithms for diagnose, therapeutic solutions, including the dental material selection. In authoring these patients the results from Questionnaire A were taken into account for maximum student acceptance.

For authoring and playing the VPs, OpenLabyrinth was selected as the platform of choice [375]. This was motivated by a series of characteristics:

- use of the Linux operating system which offers a more secure computer platform;
- Open-source license which allows installation of software without any additional cost;
- a powerful set for editing and playing virtual patients;
- cross-platform compatibility;
- compatibility with MedBiquitous standards which allows VP exchange with other systems.

The web application was installed as part of the university eLearning platform and was made available to the participating students via a shared user account.

After the completion of the two VP cases, the students were asked to fill in Questionnaire B which collected opinions regarding the impact of VP training on the acquired clinical abilities in dental material selection. Some of the most representative issues approached in this questionnaire were:

- how realistic is the simulation of a clinical case by comparison with a real-life situation;
- does the virtual patient engage the trainee in all clinical phases (e.g. history taking, physical examination, intra-oral examination, paraclinical investigations, diagnosis and treatment planning);
- has the trainee reconsidered his/her opinion related to the diagnosis and the adequate treatment plan as a result of feedback received from the simulation;
- has the ability of clinical reasoning improved as a consequence of training with VPs;
- what were the main reasons that contributed to the improvement of the clinical reasoning;
- is the VP training considered as a useful as an enhancement of traditional learning methods.

In the final phase of the study, the results of the two questionnaires were evaluated in order to establish if the student expectations were met by the VP simulations and what characteristics should these systems incorporate in order to reach a high level of acceptance among students.

Results

The acceptance of VP systems by the trainees in educational activities is an important factor contributing to a series of positive effects: increased communication abilities between the medical professional and the patient, increased capacity to deal with a wide spectrum of clinical scenarios, retention of the acquired abilities for a longer period etc.

The Questionnaire A results point out some important aspects. From the entire group of students, 21.7% did not use any virtual patients in their training or did not have any knowledge about VPs at the time of our study (Fig. 92).

The overwhelming majority of the students considers that VPs are useful in the educational process (Fig. 93). The z-test for proportions reveals a z-score of 7.60 which is considerably higher than the reference value $z_{0.05} = 1.96$. This shows the strong relevance of the VP contribution in the educational process. The most important benefit as perceived by the students is that VPs are an enhancement of the classical learning methods (Fig. 94).

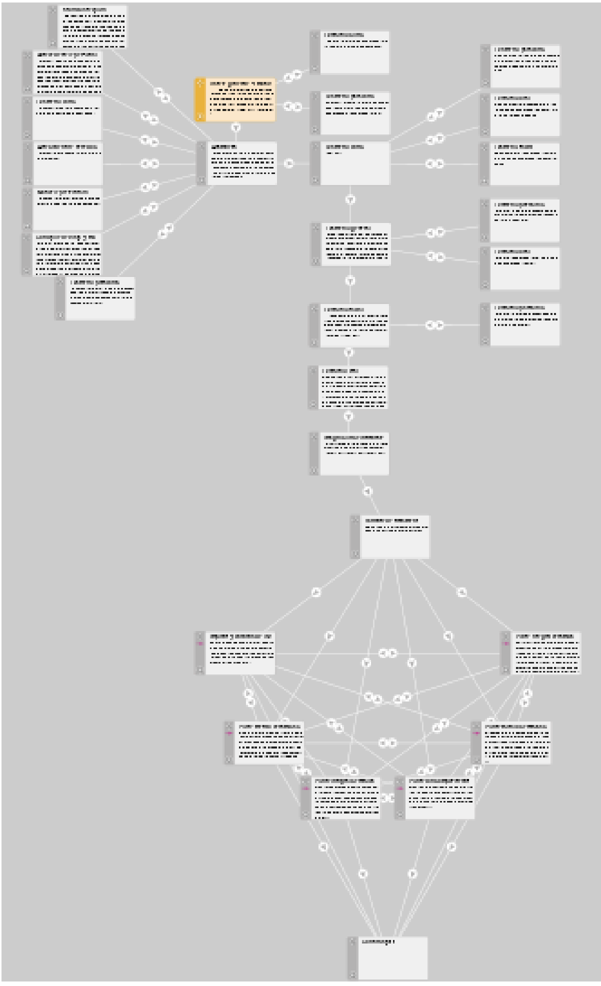


Fig. 88. OpenLabyrinth graph structure of the VP

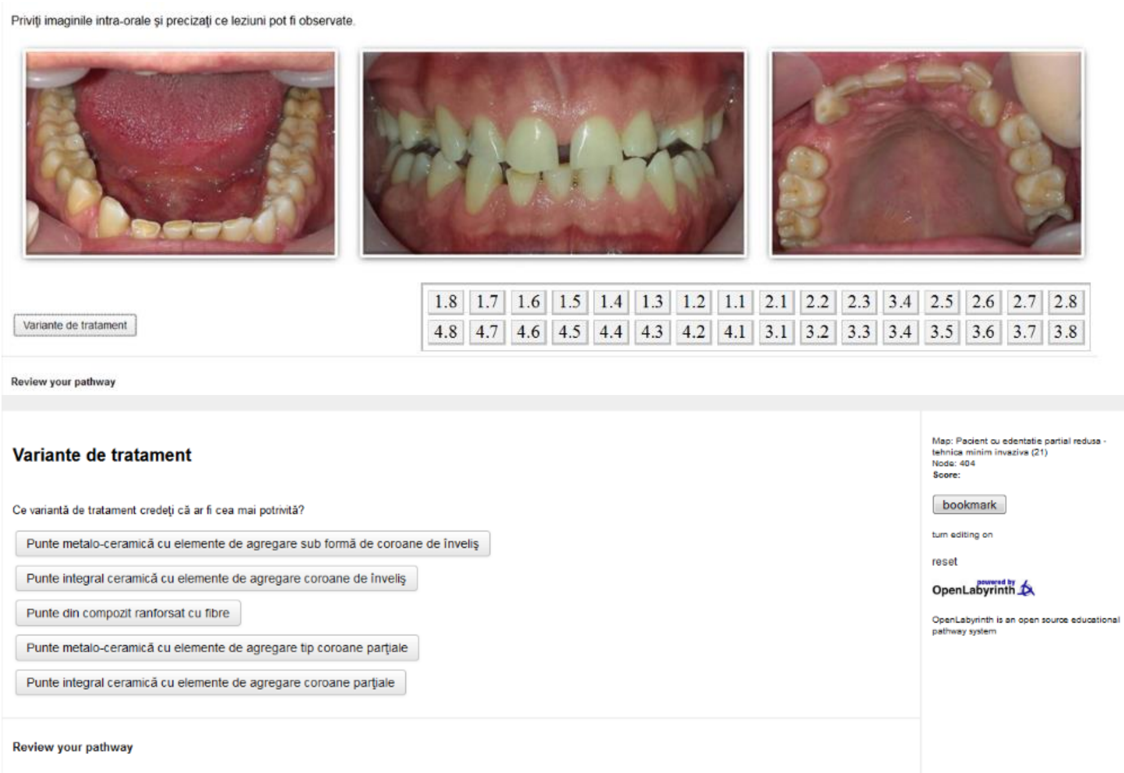


Fig. 89. Virtual patient player

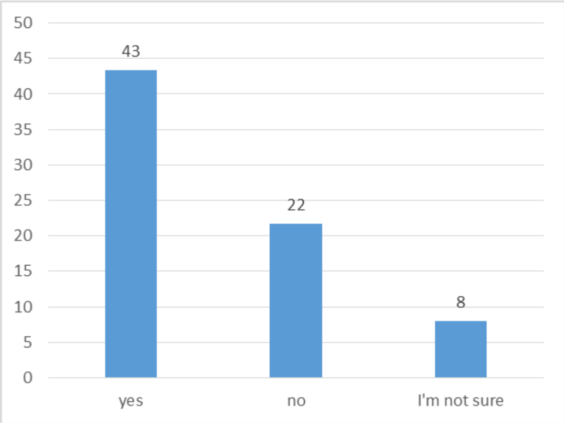


Fig. 90. Previous experience with virtual patients

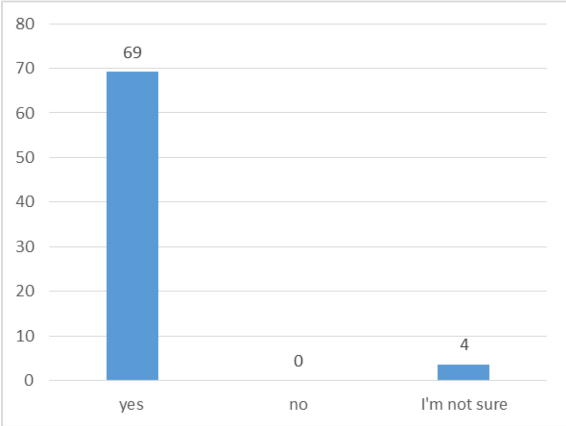


Fig. 91. Are VPs regarded as useful in the educational process?

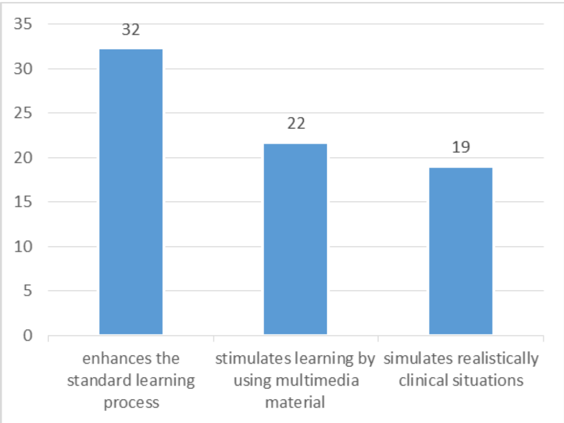


Fig. 92. Benefits of using VPs in training

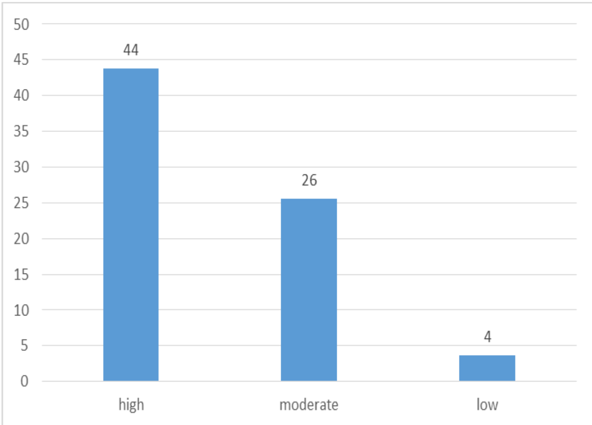


Fig. 93. Credibility of the clinical cases simulation

Questionnaire B offers feedback after completing two VP training sessions. Some of the results show that 44 students out of 73 consider the simulations having a high degree of credibility which reflects a good level of immersion and realism (Fig. 95). The z-test for proportions reveals a z-score of 7.67 which is much higher than the reference value $z_{0.05}$ = 1.96, proving a high and moderate credibility of clinical cases simulations.

When questioned about the reasons that contribute to the improvement of clinical reasoning (Fig. 96), most students mentioned the variety of clinical scenarios which is ranked even before the multimedia content. This shows that the coverage of various subjects and possible situations that can appear in real-life medical activities is an important factor in the expected effect of VP training.

Concerning the dental material selection ability, 64% of the students considered that the use of VPs is highly beneficial, while 33% evaluated them as moderately beneficial for this field (Fig. 97). The z-score is 2.47 which compared with the reference value ($z_{0.05}$ = 1.96) demonstrates a high relevance of material selection training with VPs from the student perspective.

Fig. 98 and 99 show the student perception about improvement of clinical reasoning in dental material selection, before and after completing the VP training. This indicates a very positive response of the trainees as a result of this type of training. Percentages of students considering VPs having a high impact on clinical reasoning improvement have risen from 26% (19 students) to 80% (58 students). The z-test for comparing the two proportions, outputs z-value = 6.5 and p-value < 0.0001 which demonstrates the statistically significant increase in trainee confidence after the VP-sessions. This is a very encouraging result and confirms the general impression that from the point of view of student acceptance, virtual patient systems are an important tool in teaching clinical skills in general and for dental material selection in particular.

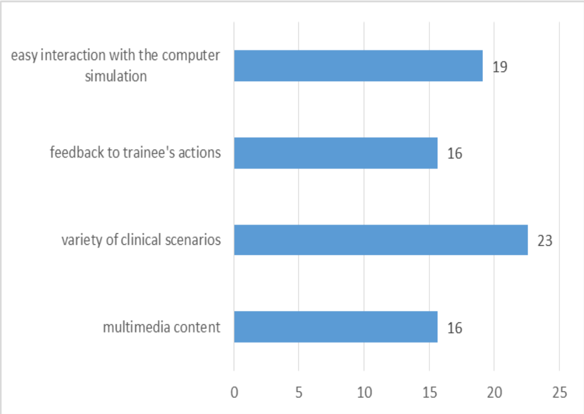


Fig. 94. Improvement of clinical reasoning

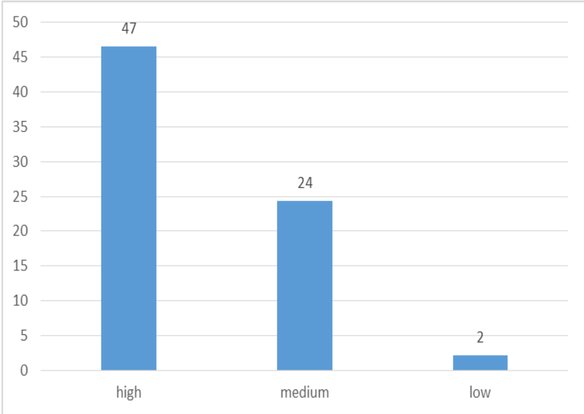


Fig. 95. Relevance of material selection training with VPs from a student perspective

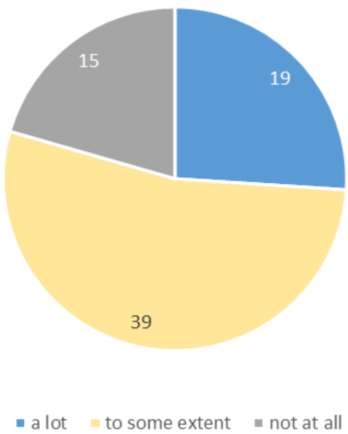


Fig. 96. Opinion about improvement of clinical reasoning regarding dental material selection before VP training

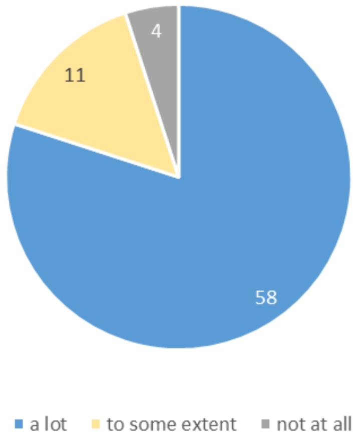


Fig. 97. Opinion about improvement of clinical reasoning regarding dental material selection after VP training

Critical opinions expressed towards the usage of VPs in the training process mention: insufficient variety of clinical scenarios to cover all subjects, the interaction with the VP has still a lot of limitations compared to the real-life situations, VPs concentrate mostly on only one pathology whereas in reality several conditions might occur at the same time.

Discussions

Recent studies [372] have shown that VPs as computer simulated clinical scenarios are effective in teaching clinical reasoning, clinical data gathering and interpretation and to some extent in acquiring communication skills and ethical reasoning. The degree of acceptance among the students is very high [398], especially with the students in the first years where the detailed information offered by a VP is not otherwise available.

Studies regarding the use of virtual patients in dental medicine [399] reveal that this is a relatively new approach in dental training. Common use of virtual patients targets the improvement of student skills in taking relevant oral health history. Most simulations concentrate on improving the psychomotor abilities of the trainees related to teeth drilling or attempt to create a virtual patient through 3D reconstruction from photographs, CT scans, X-Ray images, etc. [400], [401].

When looking at the advances in nowadays dental medicine on one hand and at the limited possibilities in some university clinics [374], on the other hand, young doctors might find themselves in a difficult situation as to which dental material should be selected, which technique or technology should be employed. This is where virtual patient platforms can fill the gaps. They can simulate various scenarios with a certain degree of realism, which prepares the future dentist for situations that he/she might encounter.

Conclusions

The simulation of clinical scenarios through virtual patients has a high degree of acceptance among students in dental medicine and in particular in the field of dental material selection. The results indicate that VP training can be an efficient tool for improving knowledge assimilation and clinical abilities that can be later used in real clinical situations. Especially in educational environments where access to various dental materials is constrained by financial restrictions or when the limited number of patients does not provide a sufficient number of cases for training purposes, the use of VP platforms can complete or, where necessary, replace the traditional methods.

It has been determined by this study that a lot of room for improvement exists, mainly in two directions: increasing the level of realism that VPs can deliver and increasing the number of simulated scenarios for a better coverage of possible situations that can be encountered in real-life. The former can be achieved by using advanced technologies in 3D visualization, virtual reality and animation which are currently used in the gaming industry. The latter requires a more consistent effort from VP authors which must receive the support of their organizations to achieve a better coverage of the topics.

2.3.2.4. Use of the OpenLabyrinth software for authoring virtual patients in dental medicine

Aim of study

Among these educational software we selected OpenLabyrinth [375]. First the possibilities offered by this software are presented, then two virtual patients were authored for exemplification, and described in the two parts of the present article. The limits and challenges of this software will make also the subject of the second part of the article.

Materials and method

The first version of OpenLabirinth was created by the Learning Technology section of the College of Medicine and Veterinary Medicine at the University of Edinburgh, but the latest versions also include the work of the Northern Ontario School of Medicine and the Aristotle University of Medicine Thessaloniki". It is an open-source system for creating interactive educational content such as virtual patients but also simulations, labyrinth games and algorithms [375].

Access to OpenLabyrinth requires nominative credentials provided by the administrator. On the homepage, one can find all the current projects of the working group.

There are different ways to create a labyrinth. Existing models can be used by duplicating those of the group (so the original will not be modified) or by importing projects via Medbiquitous (Fig. 100).

Virtual patient creation can be:

- manual: we insert the title, a description, the keywords, the type of interface and a timer if necessary;
- step by step: the first option is the same as in manual mode, the second one requires the type of PV (linear, branched or in pearl necklace) and the third one requires the start and the end scenarios.

This category contains the two components that make up the skeleton of a labyrinth: the rooms and corridors represented by the nodes and links. The visual editor (Fig. 101) is the schematic representation of the labyrinth. It allows the creation of nodes and links that form the labyrinth structure. One can modify the content of the nodes (title, text, image, multimedia) and their characteristics (priority, mandatory). One can also establish links between the different nodes, represented by arrows.

Nodes are the units of the labyrinth and contain what the user will see when exploring as a "card". It is important to understand that, for example, "node 1" contains all data relating to "card 1". They can be exploited either with the visual editor or with the menu of the nodes. There is the possibility to add (add a node), modify their content (direct), delete (delete) and preview of the final rendering (view). The option to edit links is also present. Nodes are the representation of the situations through which the user will travel during the execution of the scenario.

The link is what connects one node to the other. There are different types (hypertext link, drop-down menu, text to enter) but the easiest to use and create, is the button which the user will only have to click to proceed to the next node. In addition, links can be one-way or two-way. The linker allows to visualize the different links uniting the nodes, to modify them or to add them. Options allow the creation and integration of items within nodes, questions, illustrative objects, and counters.

The virtual patient software allows to question the user whether it is for learning or for evaluation. We can proceed in two ways:

- without the question editor, we consider a first node containing the question, itself linked to other nodes that contain the answers. With this process, questions are necessarily simple complements.
- with the question editor, you can create questions and integrate them inside the node. There are many possible forms (text entry, multiple choices, drop-down menus, answer to order ...).

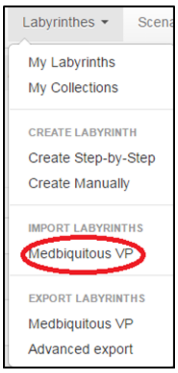


Fig. 98. Import option

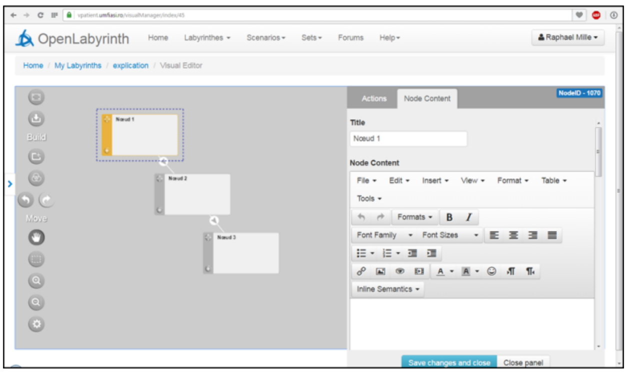


Fig. 99. This labyrinth has three nodes with a link, represented by an arrow, going from node 1 to node 2 and a link from node 2 to node 3.

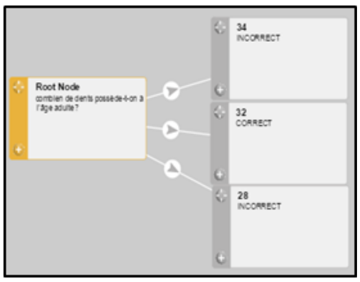


Fig. 100. Question created with nodes and links

For multiple-choice questions, one sets the question and then inserts the answers by determining which ones are correct and which ones are not. One can also add a score and a comment that will appear when the user selects the answer. When the question is finished, the software creates a marker in the form [[QU: XX]] that can be integrated into the node (Fig. 103).

For other forms, text entries are easy to set for numeric values, but when one asks for written answers, they must be able to anticipate all possible answers including spelling, word order and synonyms.

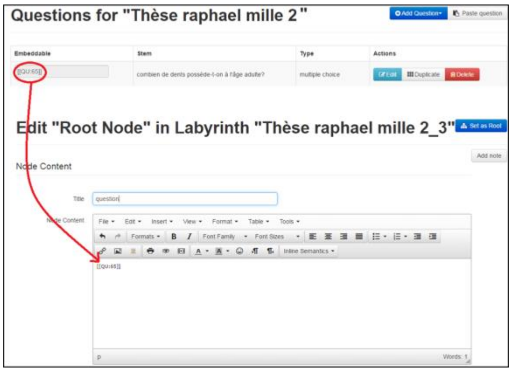


Fig. 101. Inserting the marker in the node

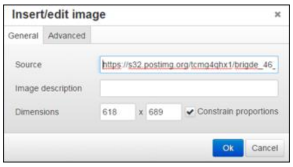


Fig. 102. Image editor

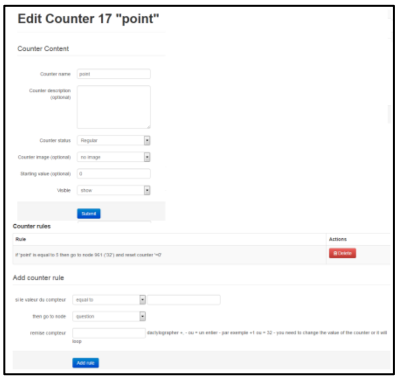


Fig. 103. Counters

OpenLabyrinth does not host images and videos itself. Indeed, it is not yet possible to insert these contents directly from the local computer. It is necessary to first upload them (download on a computer or a remote server) using many websites that do this for free (http://www.hostingpics.net; https://postimage.org). Once the link of the object obtained, it is enough to copy it in the editor of image or video in the contents of the node (Fig. 104).

A point system assigned to each user’s choice can be used by giving values to the different responses. The score can be purely indicative, for the evaluation of the user, or allow to lock access to certain nodes if the score is too low. Therefore, rules must be added to the “add counter rule” counter, in the form of “If the counter is equal to 5, move to node X” (Fig. 105). These counters can also be used to quantify prices, or health indices (heart rate, blood sugar, pain).

Results

Patient 1

The different features and options of the software were used in authoring the two virtual patients described in the two parts of the present article. For all the patients the informed consent was obtained.

The first virtual patient offers a diagnostic and treatment plan in its first part, and then the user must review the various prosthetic options and criticize the choice to make. Finally he has to face the complications.

The VP has 22 nodes, 40 links and 20 questions. The structure is also in pearl necklace. There are also three sections: (a) anamnesis, (b) diagnosis and treatment plan, (c) prosthetic treatment and complications (Fig. 106).

The first node shows the patient picture and three choices are given: continue the anamnesis, do the intraoral exam or check the X-ray.

(a) In the *anamnesis*, the user learns that the patient has undergone radio- and chemotherapy and is asked a question related to the oral side effects of these treatments (Fig. 107) and then the next sequence continues.

The intra-oral examination reveals numerous lesions. The question raised here is related with the etiology of these lesions and thus resumes the discussion with the patient (Fig. 107). The evaluation of the metal-acrylic bridge is issued in the card 4 and supported by the X-ray. Students tend to look at X-rays very quickly, sometimes even before speaking to the patient.

Observations: Note that the first node (in yellow on Fig. 106) has only one classical link while three choices are possible. To enable navigation, a counter was used, which was inserted into the first node, and assigned rules (Fig. 108). Each answer to the question "what do you do" generates a score when you click on it and this score corresponds to the next node. For the transition to the diagnosis part, the correct answer to the question of the last node (*"What type of para-clinical exam would you recommend?")* leads directly to the first card of the second part.

The advantage of this method is to avoid influencing the user in his choice of answer, in fact the classic links appear in the form of buttons and clicking on it, if the answer is wrong, leads to another node and force a backtrack.

(b) In the *diagnosis* part, each quadrant of the oral cavity was presented into a node with clinical and radiological images and a question. The first card of this part (Fig. 106) shows the orthopantomography of the patient and asks to look at each quadrant/segment. From this step one must choose from the six segments of the dental arch (Fig. 106 - cards 8, 9, 10, 11, 12, 13) and answer the questions asked. If the button "solution" is clicked on before having visited all the dental segments, a message tells us to finish the exam.

In the 1st segment (Fig. 109) remaining roots are present and the question is what should be the approach. The link to the first segment no longer appears because it has already been visited. It is the case for the each visited node. For the anterior segment the question is related with the type of the required restoration: direct restoration (composite), indirect (bridge) or surgical. For the second quadrant, the images have already been encountered in the first part of the map if the user has chosen to view the X-ray directly (Fig. 109). We no longer look here at adaptation but the mesial extension that is always a questionable element that must be justified. In the 3rd quadrant there is an edentulous space. The images are presented for information purposes, but the student should start considering a removable prosthetic solution. In the inferior anterior sector, one can note the dental and periodontal lesions (abrasion, calculus, dento-alveolar incongruence). Saving a tooth for prosthetic reasons is a complicated problem and a general perspective is needed. It will sometimes be necessary to make concessions in order to keep a damaged tooth. This is the case here because it is a terminal tooth that might ensure the stability of a removable denture.

By visiting all the cards, one now has access to the last part.

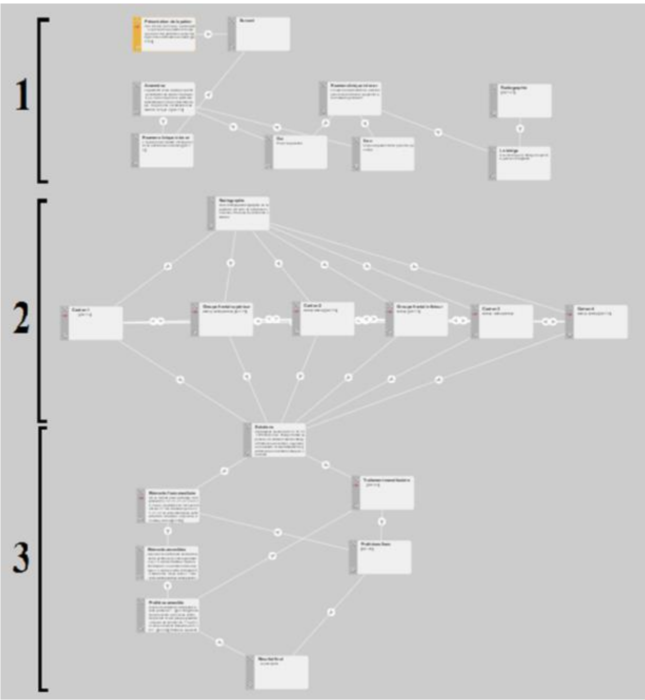


Fig. 104. Pearl necklace structure of labyrinth (map): 1. anamnesis; 2. diagnosis; 3. prosthetic solution

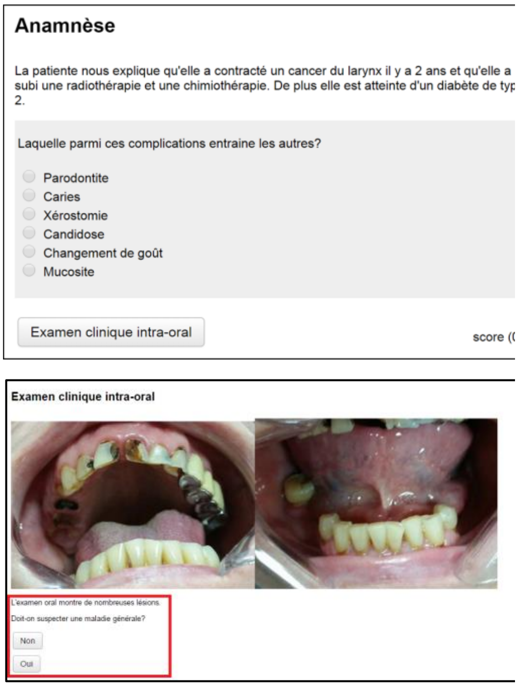
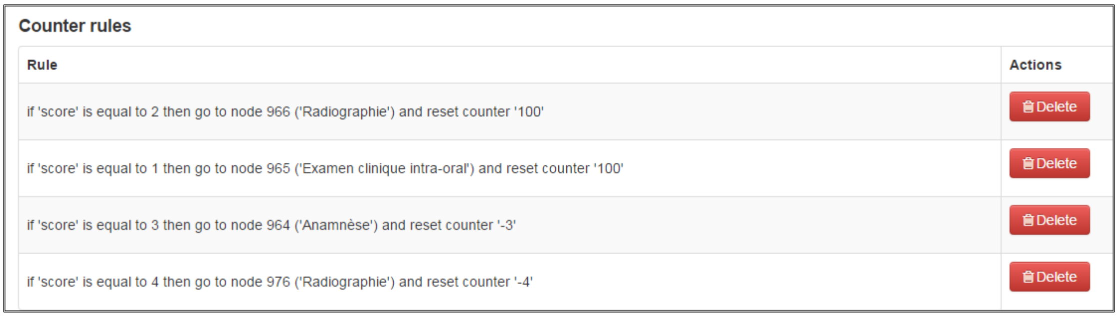


Fig. 105. Anamnesis and intra-oral clinical examination



Counter rules

Rule	Actions
if 'score' is equal to 2 then go to node 966 ('Radiographie') and reset counter '100'	Delete
if 'score' is equal to 1 then go to node 965 ('Examen clinique intra-oral') and reset counter '100'	Delete
if 'score' is equal to 3 then go to node 964 ('Anamnèse') and reset counter '-3'	Delete
if 'score' is equal to 4 then go to node 976 ('Radiographie') and reset counter '-4'	Delete

Fig. 106. Rules of the counter

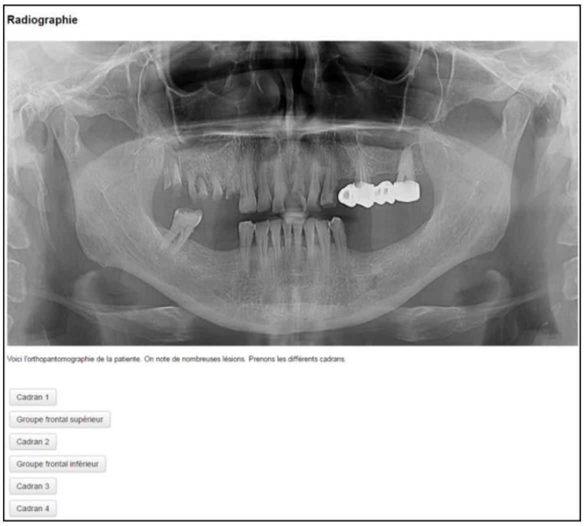


Fig. 107. OPG and quadrant selection

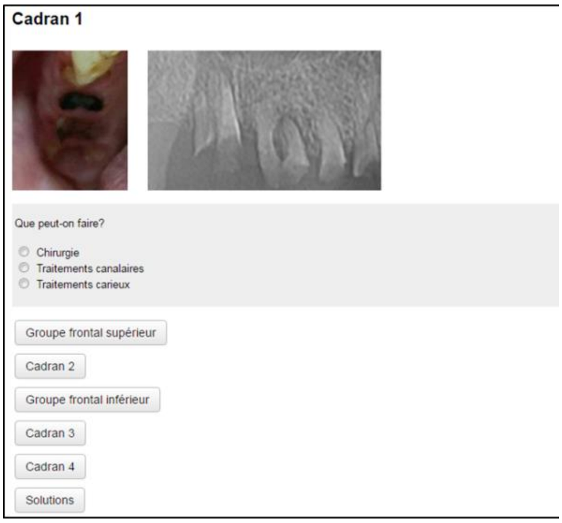


Fig. 108. Quadrant example

Observations: In order not to go around in circles and return to previously visited cards, the option "prevent revisit" has been activated for the dial nodes (Fig. 111). This will no longer display the link to a card already seen. The restriction of access to the next part is done by programming the node "solution" with the option "node conditional" (Fig. 111). You must have visited the nodes 977, 978, 979, 980, 981 and 982, corresponding to the quadrant charts, to be able to continue, otherwise the message "complete the examination to access the diagnosis" appears.

(c) The prosthetic solution part begins by giving the principal directions of the treatment: surgical, fixed restoration and removable denture. One has the choice to start with the maxillary or mandibular prostheses, both having a fixed part and a removable part.

For the mandible an exercise of differences between the removable partial denture diagram and the actual denture is proposed (Fig. 112). A question is asked about the utility of adding fixed elements (Fig. 113).

For the maxilla there is a question about an impression for inlay-core (Fig. card 116), then a correspondence between removable denture elements and their schematic representation (Fig. card 117) and finally it is asked to select the correct terminology to name the removable partial denture (Fig. card 118).

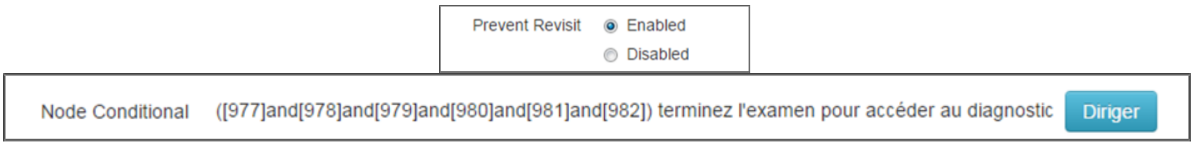


Fig. 109. Access conditions to the "solution" node

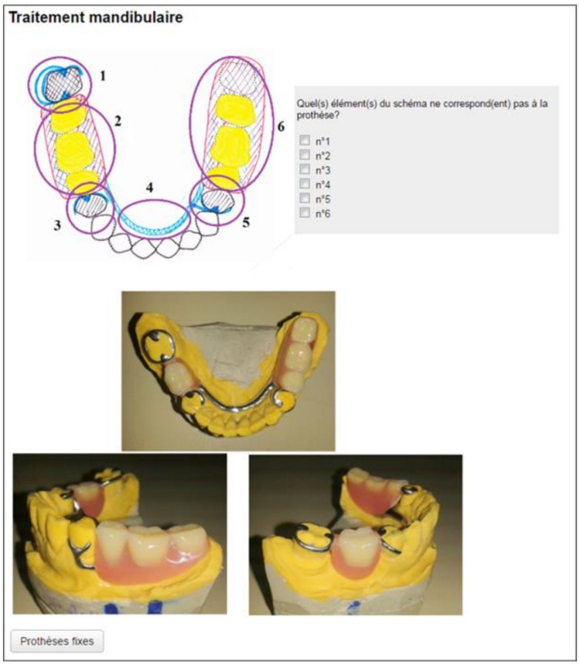


Fig. 110. Exercise of differences

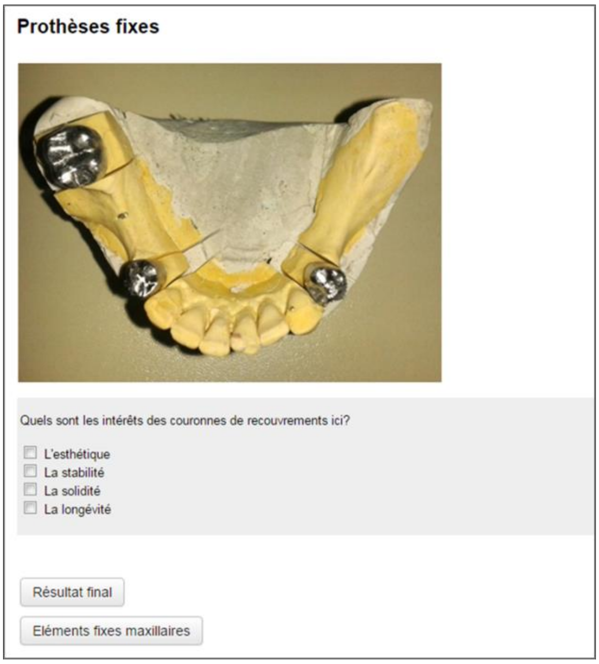


Fig. 111. Exercise of differences

One can always criticize and find defects in an impression, here the absence of discharge groove been obvious, but it was decided to ask what this impression corresponds from a prosthetic point of view.

For the removable partial denture, a mapping exercise is proposed between prosthetic components and their schematic representations (Fig. 114). The map finishes with a question of terminology (Fig. 115) where one has to select the correct definition corresponding to the restoration.

The last card can only be accessed if all cards of this part have been visited. We obtain the final result with the comparative before and after.

Fig. 112. Correspondence exercise

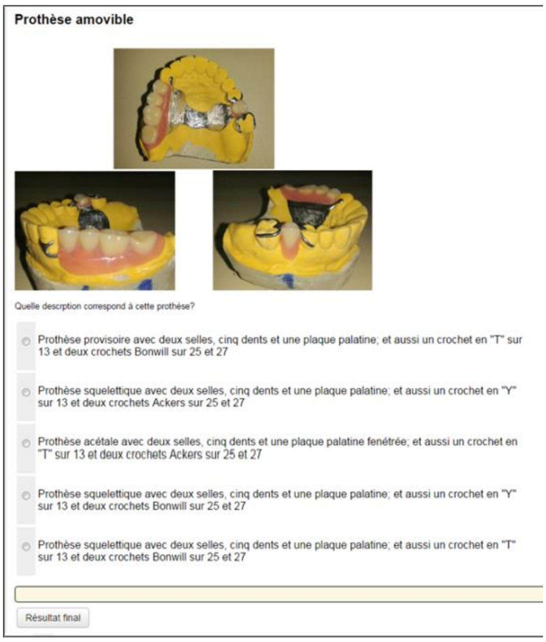


Fig. 113. Terminology exercise

Observations: We encountered different problems for the development of the exercises. Indeed, it is not possible to embed images directly into questions. It was thus necessary to create the answers independently of the questions and the images and to make a work of layout with the help of tables. Then you must know that the number of characters per response is limited, so we also had to use tables. As for the second part we used the options "prevent visit" and "node conditional".

B. Patient 2

For this virtual patient, the user has to determine the diagnostic and devise a treatment plan in the first part, and then various treatment solutions must be reviewed and a critic analysis of the chosen solution must be made. Finally, the user has to evaluate the possible complications.

1. Characteristics of the VP

There are 22 nodes, 40 links and 20 questions. The structure is based on a pearl necklace model. The VP is structured into three sections: diagnosis and treatment plan, prosthetic treatment and complications (Fig. 116).

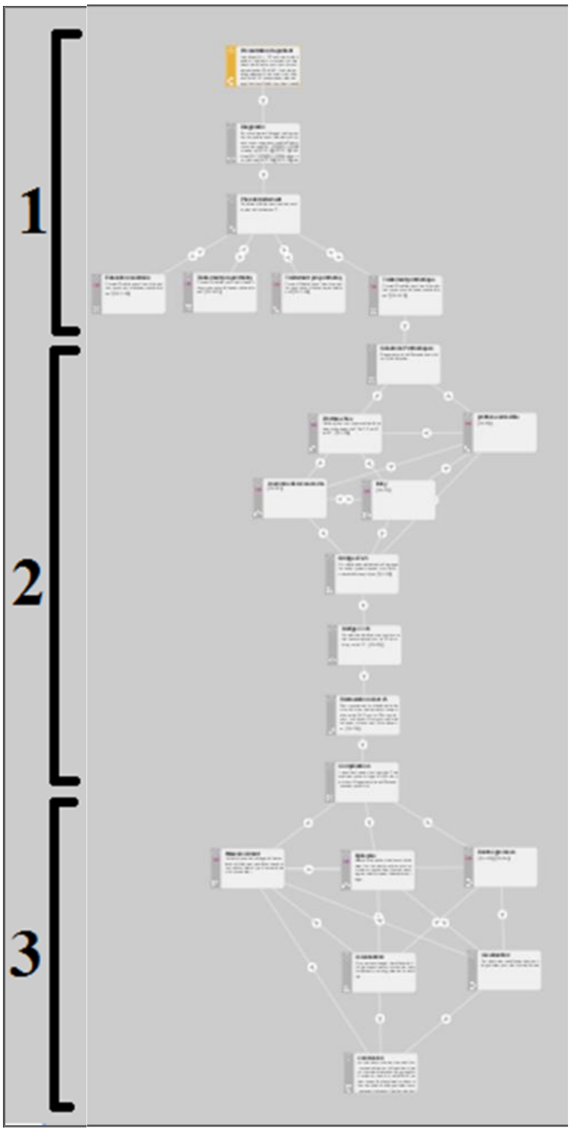
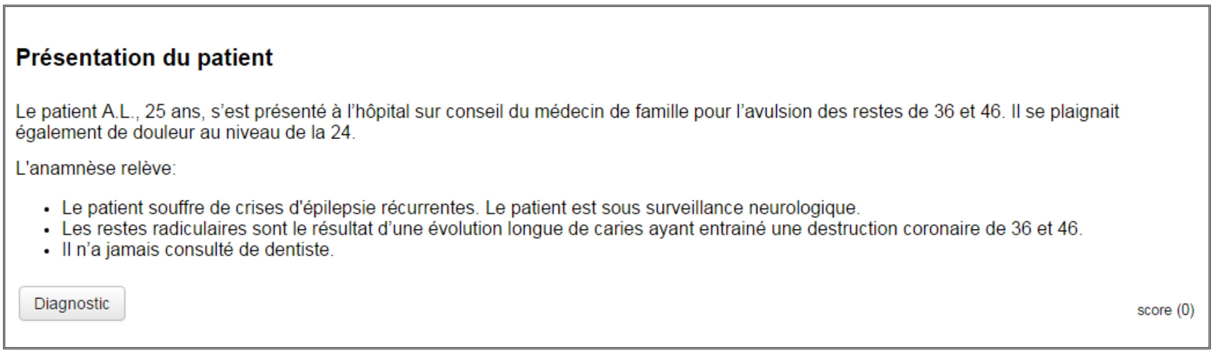


Fig. 114. Pearl necklace structure of labyrinth. 1. diagnosis and treatment plan; 2. prosthodontic solution; 3. complications

2. Case description

a. Diagnosis and treatment plan

As with all patients, virtual or not, we start with general data and history (Fig. 117). We note here the epilepsy that needs to be considered.



Présentation du patient

Le patient A.L., 25 ans, s'est présenté à l'hôpital sur conseil du médecin de famille pour l'avulsion des restes de 36 et 46. Il se plaignait également de douleur au niveau de la 24.

L'anamnèse relève:

- Le patient souffre de crises d'épilepsie récurrentes. Le patient est sous surveillance neurologique.
- Les restes radiculaires sont le résultat d'une évolution longue de caries ayant entrainé une destruction coronaire de 36 et 46.
- Il n'a jamais consulté de dentiste.

Diagnostic

score (0)

Fig. 115. Presentation of the patient

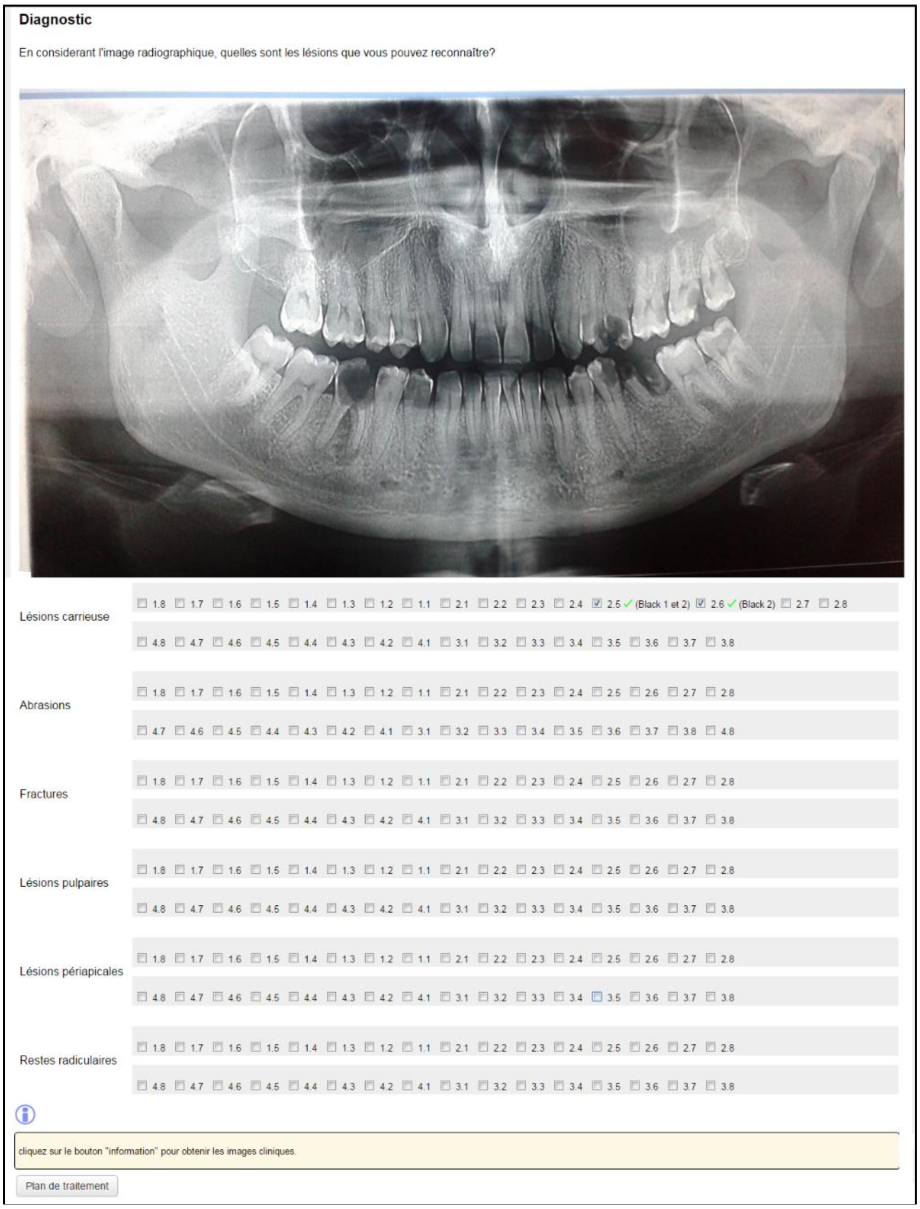


Fig. 116. Diagnosis table

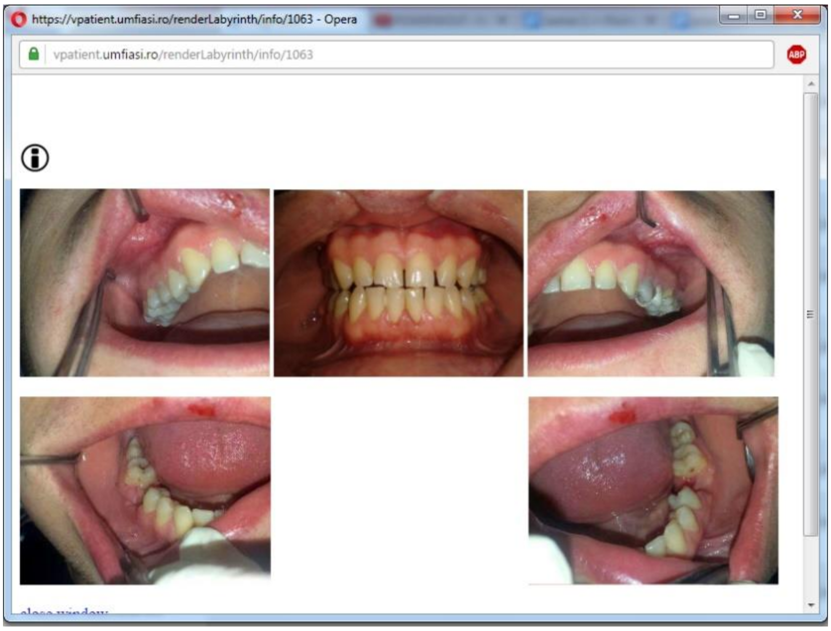


Fig. 117. Clinical images

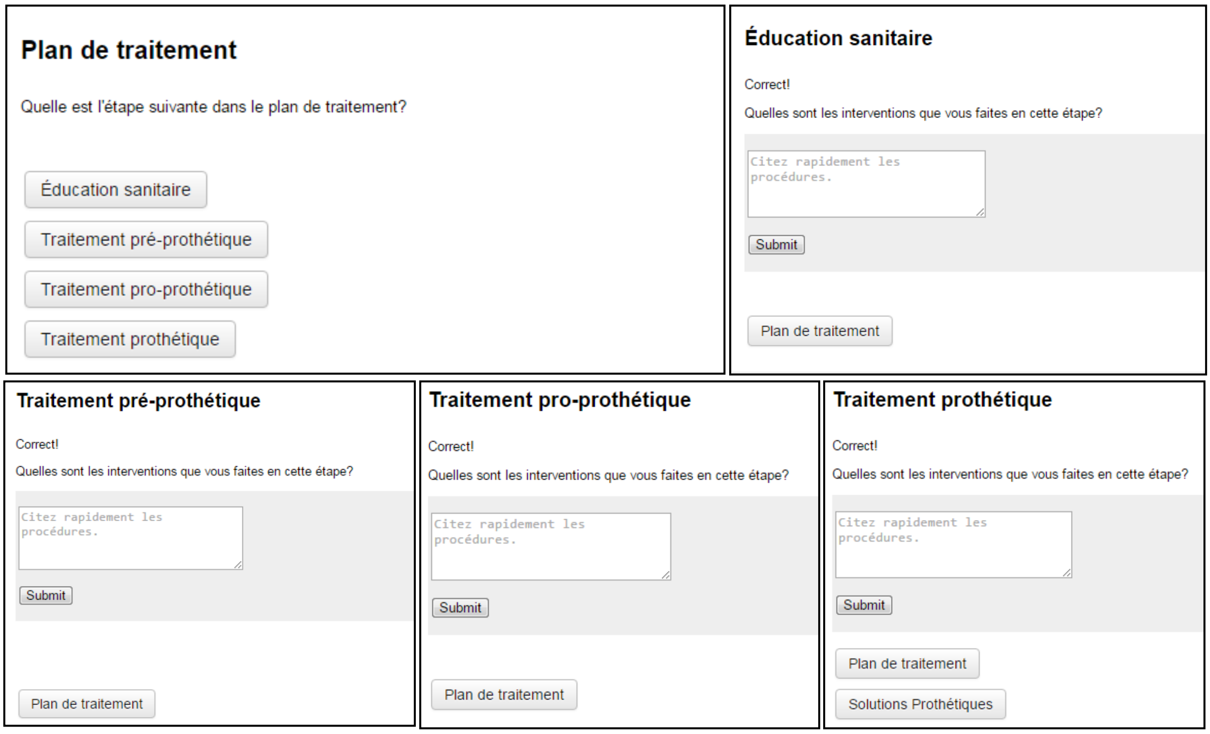


Fig. 118. Treatment plan cards

- *Diagnosis*

This card (Fig. 118) shows the classic diagnostic table. The panoramic X-ray is presented, and the clinical images are accessible with the "information" button (Fig. 119). The answers are programmed so that they appear “good” or “bad” but this can be modified leaving the answers blank for the user to make his own diagnosis. In addition, this card can be adapted to other patients, unlike other cards where the questions are more specific. Only the images should be changed in that case.

- *Stages of the treatment plan*

The stage order must be kept, so a step can only be accessed if the previous one has been completed (Fig. 120): health education, pre-prosthetic treatment, pro-prosthetic treatment and finally prosthetic treatment.

We created open-ended questions to provide more freedom and avoid influencing the user. However, this requires more control by the author because the software does not automatically recognize a good answer. When all the steps of the treatment plan have been completed, one can go to the second part.

This first part can be used in the beginning of any virtual patient because we used general questions and not specific ones. Simply by editing the patient data and the images, this first part can be included in another virtual patient.

b. Prosthodontic solution

- *Therapeutical options*

Through these cards (Fig. 121, 122) the user is asked about the different types of possible restorations: fixed or removable partial denture, with different retainers. The questions are about the indications and contraindications, pros and cons.

The user is gradually guided to the correct solution because each response is commented in parentheses and the result is immediately known with one , for the right answers, and one , for the wrong ones.

- *Therapeutical solution*

In what follows, we use images of different stages of restoration fabrication. (Fig. 123, 124). The questions relate to the reasons for the made choices and the employed materials.

- *Observations*

The progression in this part is rather linear and the user does not make a real therapeutic choice, but he must understand what motivated us for the different procedures.

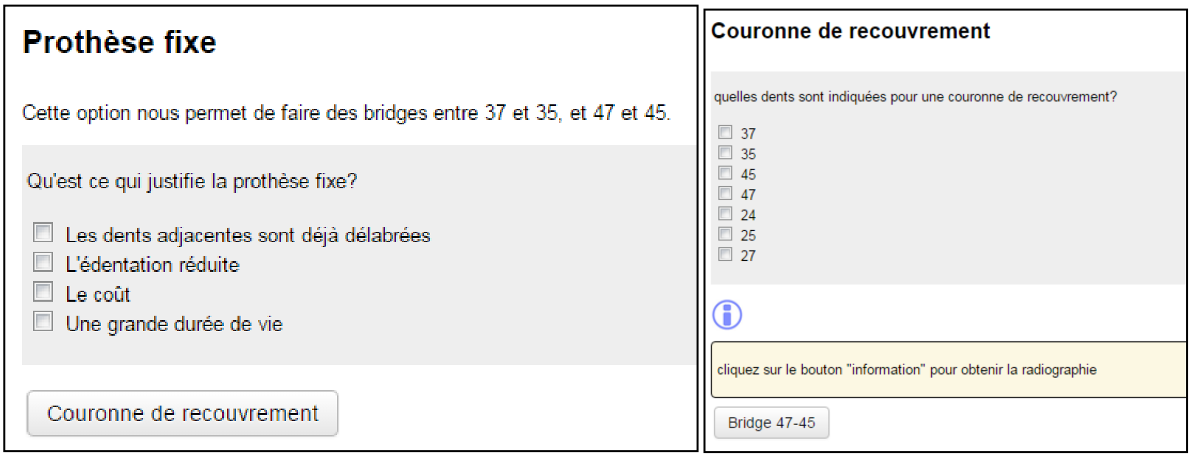


Fig. 119. Cards with prosthetic solutions

c. Complications

This part contains few questions regarding the evolution and complications of the case, considering the general condition of the patient but also the local conditions and procedurals errors (Fig. 125). It is always useful for students to deal with complications in the controlled environment of the VP in order to get some prior experience that will help them later with the real cases. For the loose bridge scenario, the user is asked to give some possible reasons and to come with alternative solutions (Fig. 126).

- *Observation*

This part is relatively poor in questions and pictures because it is more of a reflection on the monitoring and anticipation of the consequences of a prosthetic treatment. The bulk of the work was done earlier, in the first and second part.

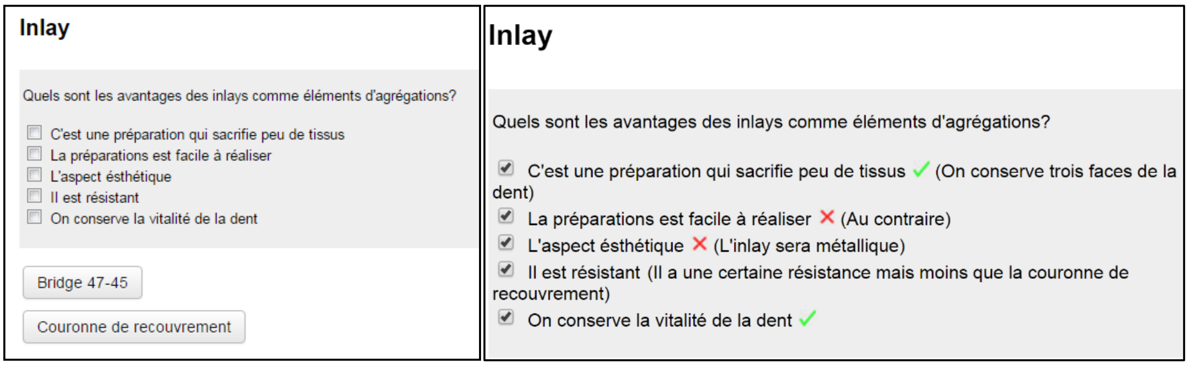


Fig. 120. Cards with prosthetic solutions

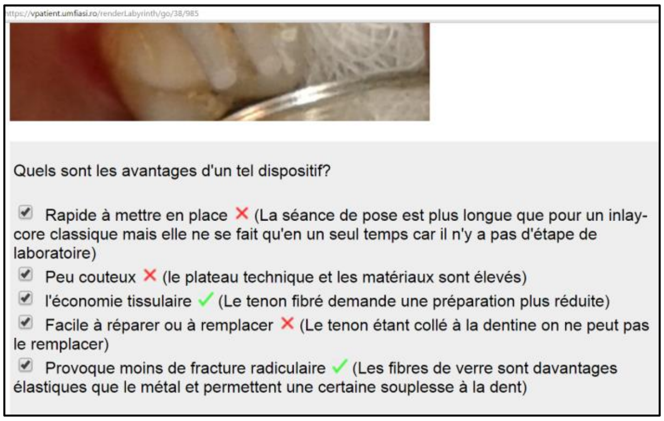


Fig. 121. Question with commented answers

Fig. 122. Metal frameworks of the bridges

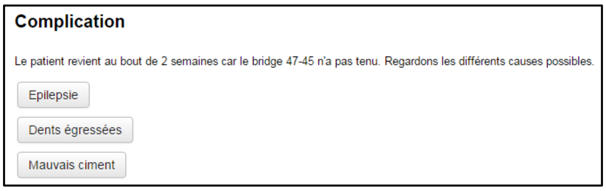


Fig. 123. Conclusions

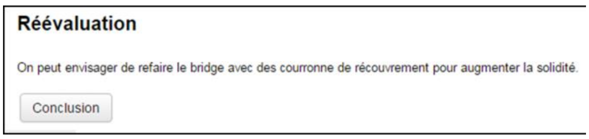


Fig. 124. Re-evaluation

Discussions

The two presented virtual patients are not assessment tools but rather learning ones because the answers are provided directly with a comment. However, it is possible to add a counter, to hide the correct answers and to assign them points (for example 1 point for the good ones and -1 for the bad ones), so that at the end of the session, the user will have an accumulated score.

One could also use the structure presented in Fig. 118 on the diagnosis as a computer aid and check the information during the examination of a real patient.

We can also imagine a tool for teaching prevention to young children [402] and adults [190, 191] with hygiene advices: how to brush the teeth, how many times per day, in order to prevent tooth decays and periodontitis etc.

In the is virtual patient, it has been worked on the attractive side. We have diversified the iconography: intra-oral clinical photographs, impressions, models, prosthesis diagrams, and types of questions: simple choices, multiple choices, correspondence exercises and differences. For the latter, the existing tools (questions, tables) have been exploited to obtain a form that is not proposed directly. The proposed themes are mostly access on the prosthetic, but the questions are almost all different to avoid weariness [403]. Finally, we have optimized navigation with the options to avoid backtracking and repetition of the nodes with the conditions of access to the nods and the "prevent revisit".

The structure of the second virtual patient is designed to be adaptable and reproducible for other virtual patient with a framework for diagnosis, treatment plan and complications.

Health simulation has advantages and disadvantages [366] for both the student and the teacher.

Benefits for the student:

- interactive and attractive content;
- resources are varied and adaptable to the level of the student;
- reproducibility of the patient;
- elimination of apprehension towards the patient to focus solely on the diagnosis;
- absence of physical danger, errors are harmless and have no real consequences;
- they help in developing global decision-making and increase confidence and coherence;
- they can simulate rare cases, difficult to find during real clinical training;
- student advances at his own pace independently of others;
- they allow a large scale dissemination;
- possibility to develop statistics on the received responses.

Benefits for the teacher:

- formation of a potentially unlimited number of students;
- reduced logistical constraints as teaching programs no longer depend on hospitalized cases and thus the cases can be prepared well in advance;
- possibility to follow the evolution and learning strategies of the student using a history;
- possibility to exchange in real time or postpone with the student;
- training medium is sustainable and updatable.

Disadvantages for the student:

- computer literacy can be complicated;
- the possibility of computer bugs and hardware failure;
- the management of autonomy;
- motivation management can be complicated.

Disadvantages for the teacher:

- hardware and software investment;
- frequent software updates might be necessary;
- no control over the motivation of the student;
- content creation can sometimes be difficult with some topics.

A virtual patient cannot currently substitute a real patient because the human side is absent in the software and also the random character of a pathology or treatment is absent. In addition, the development and operation of the software means costs, time, resources and qualified personnel in many areas (IT, logistics, medical).

Conclusions

1. The images

Dentistry primarily uses observation in clinical examination. With the virtual patients, as we conceived them, that is to say, without mannequins or physical support, everything depends on the observation of images. It is therefore necessary to gather all the photographs necessary for the elaboration of the patient, which constitutes a first challenge. Then the images must be relatively interesting; with an unusual procedure, an error or a remarkable element, something that makes it possible to ask a relevant question.

2. The questions

We mainly used multiple-choice questions because they offer useful options for learning and they are easy to set up. On the other hand, they pose different problems: one cannot argue or qualify an answer, in an evaluation system, one will necessarily avoid the wrong answers to the detriment of an explanation and conversely, in training mode, one will tend to check everything to see all provided explanations. Moreover, we cannot use very long answers, as previously mentioned, and so we must find short meaningful descriptions.

Regarding the topics and the wording of the questions, we must point out that multidisciplinary collaboration is not only important, but it is indispensable. To propose a question in a specific field, you need to have an overview and comprehensive knowledge about the subject so as not to make mistakes or omit some elements.

3. The labyrinth

The authoring of an ideal and complete virtual patient where the user could make all the decisions is extremely complicated. Indeed, the images taken from real patients represent a single procedure. For example, if a decay is treated with composite filling material, we will not be able to have the same image with amalgam. This is a simple example but if we try to imagine this limitation with all possible prosthetic variants, we have to conclude that it is impossible to have images of all the prostheses for the same one patient.

However, considering all the limitations and the downsides of the VP system it is our opinion that the advantages exceed by far the disadvantages and that the large-scale introduction of VP training and assessment tools in universities and training facilities is a great complementary measure for improving performance in education.

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SECTION II.
FUTURE DEVELOPMENT PLANS REGARDING TEACHING CAREER AND RESEARCH ACTIVITY

For the future I intend to focus on each of the three main pillars of my career – medical profession, teaching and scientific research. I will keep myself up-to-date with the current development in the field and I will continuously improve my practical skills. Another direction that I consider very important and with equal impact on all three activities is finding resources for infrastructure improvement, for the development of dental equipment and technologies employed in our field. I will persevere in developing multidisciplinary research teams and establishing collaboration with equivalent departments in other universities to create partnership projects and research networks. The research results will be presented in national and international scientific events and published in ISI Web of Science ranked and IDB indexed journals.

1. FUTURE DIRECTIONS IN MEDICAL DENTAL ACTIVITY

I regard the dental medical activity as the foundation on which the didactic activity with the students is built and as the source of original ideas based on which research can be initiated. It is mandatory to keep on studying and attending professional national and international conferences and scientific events organized by prestigious dental associations in my domain of interest. Moreover, as a member of the academic staff, I feel compelled to be a vector of dissemination of the latest advancements in prosthodontics and DSSS and to update diagnostic and treatment protocols based on global trends.

I will continue to persevere in finding and applying the best treatment for my patients, in the context of modern trends of minimally invasive dentistry. Prosthodontics is at the forefront of innovation and the advancement in this field is the most effervescent in terms of biomaterials and technologies. Materials need to be more resistant and esthetic in thinner layer to prevent the dental tissues sacrifice. Materials like bioactive materials, fiber-reinforced composites (FRC), graphene, polyether ether ketone (PEEK), zirconia, lithium disilicate or hybrid ceramics and technologies like CAD/CAM, 3D printing and rapid prototyping, dental laser will continue to be in my arsenal of first intention in restoring the integrity of teeth and dental arch.

2. FUTURE DIRECTIONS IN RESEARCH ACTIVITY

Scientific research is becoming increasingly important, a fundamental element in defining a teacher. It develops thinking based on logical reasoning, on the power of observation, on creativity, on the ability to analyze and synthesize and, last but not least, on the innovative spirit, which makes things progress.

2.1. DEVELOPMENT OF RESEARCH DIRECTIONS

2.1.1. Research in the field of fixed prosthetic restorations with focus on biomechanical behavior

This research direction is a continuation of the studies I have carried out so far and which have materialized in various publications. It is motivated by the continuous pressure for improving the life-span of dental restorations. New biomaterials and restorative techniques are not an absolute guarantee for therapeutic success, especially in the existing competitive system, in which the aggressive campaign and less the performance of materials seem to be the criterion of choice. In fact, not infrequently over time, the medical world has faced situations in which drugs, materials, concepts or principles, which seemed well established, had to be reconsidered. In the context of a wide range of variables, specific for oral biological and biomechanical conditions, the long-term performance of an indirect dental restoration is rather difficult to predict, the biomechanical failure of restorations being one of the most incriminated factors. In the pursuit of minimally invasive restoration, the dental market is flooded with new materials and technologies making the therapeutic choice even more difficult.

The aim of this direction is to use complementary methods that complete each other to give the real picture of biomechanical phenomena. For this, we plan the development of 4 models, both conceptually and practically: ***clinical***, ***physical***, ***mathematical*** and ***computational***. Each of the four models will bring new elements in understanding the biomechanical phenomenon and also to support the validity of the other models. Thus, the data obtained through clinical observations and investigations will be corroborated with the data to be obtained in the laboratory by simulating the clinical situation (reproduction of oral structures important in biodynamics, simulation of mandibular dynamics, with reproduction of demands on investigated structures), with analytical data provided by expressing the investigated phenomena (wear, fracture, deformation, etc.) by mathematical equations and with the data obtained by computer simulation of the investigated state. Understanding the phenomenon will certainly offer a new perspective on the therapeutic approach, perhaps reformulating some concepts and rethinking some theories.

The research is aiming to continue to evaluate the biomechanical behavior of odonto-periodontal tissues (enamel, dentin, periodontal ligament, alveolar bone), direct restorations (hybrid composite resins, ceromers, nanocomposites) and indirect restorations (single unite restorations, fixed dental prostheses of different materials) starting from nanostructural analyzes and ending with analyses in different conditions of making and function.

In this regard, I will direct my research toward:

- *Fundamental in-vivo and ex-vivo studies* on the structure and biomechanical behavior of oral tissues and dental and prosthetic reconstructions using Scanning Electron Microscopy (SEM), Scanning Probe Microscopy (SPM), Atomic Force Microscopy (AFM), Energy-Dispersive X-ray Spectroscopy (EDSX), Environmental Scanning Electron Microscopy (ESEM), Cone Beam Computed Tomography (CBCT) - elaboration of a ***clinical model***
- *Laboratory studies* of biomechanical behavior of oral tissues and dental and prosthetic reconstructions - elaboration of ***physical model*** and ***analytical model***
- *Computerized analyses* regarding the biomechanical behavior of oral tissues, dental and prosthetic reconstructions using 3D modeling and FEA, discrete element analysis (DEA) and extended finite element method (XFEM) - elaboration of the ***computational model***.

Thus, the research aims to analyze micro- and nanostructural and to reproduce oral structures of importance in biodynamics, simulate mandibular dynamics, simulate different stages of making the restorations (ceramic firing, light curing, etc.) with the reproduction of stress on the investigated structures and evaluation of the obtained results. The consequences of the stress can be: wear, deformation by ceramic firing or by stress, fracture of substructures and restorations, resorption / atrophy of the prosthetic field, traumatic tooth injuries – non-carious cervical lesions, periodontal injuries, etc.).

Simulation methods such FEA, DEA and XFEM were proven to be a valid alternative for the analysis of stress distribution, crack initiation and fracture pattern of 3D models. FEA and XFEM have also been employed in dental research for a variety of materials and case scenarios such as the contact-induced damage in layered materials systems and the failure of enamel, dentine, restored teeth and ceramic crowns.

Validation of computerized analyzes by FEA, DEA and XFEM (numerical simulation verified and validated by laboratory experiments), through substantiated interdisciplinary biomechanical studies, will allow the extension of the aria of application of numerical modeling and the creation of a library of 3D models that can be used as a platform in any type of mathematical simulation and modeling.

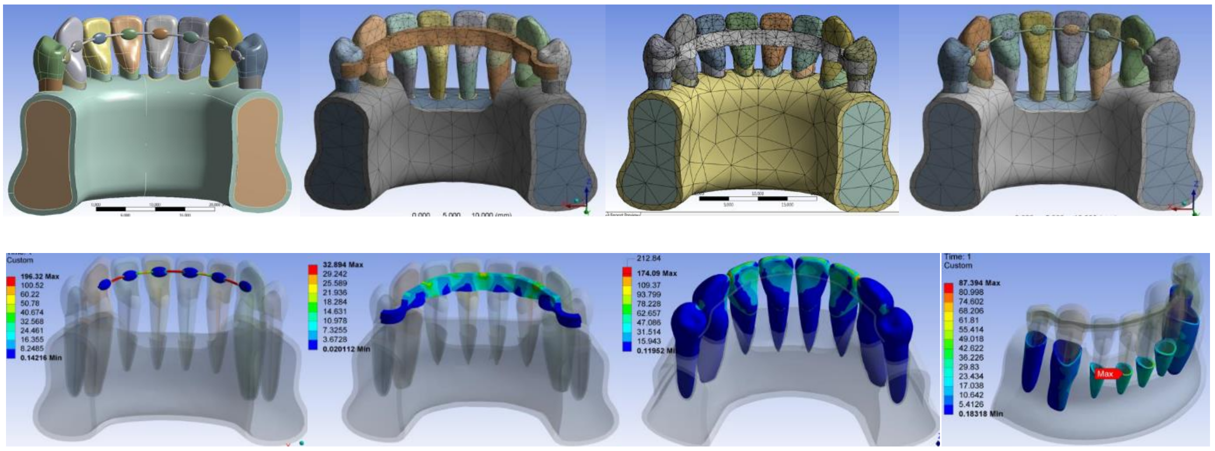

Fig. 125. Finite element analyses of biomechanical behaviour of fiber-reinforced composite periodontal splints

2.1.2. Factors involved in homeostasis and dishomeostasis of stomatognathic system

The balance of the stomatognathic system is tributary to local, loco-regional and general factors. I intend to continue the research in the directions mentioned in I.1.3. I will focus on the dynamic interplay between chronic inflammatory rheumatic disorders, periodontal pathology and TMJ disorders. My priorities will be related with all the coordinates of the dysfunctional syndrome of the stomatognathic system and minimally invasive prosthetic therapy in functional and esthetic context. I will continue to identify and correct the factors that can alter the results of prosthetic treatment, extending the area of corroboration of data in the interdisciplinary sphere.

2.1.3. Information technology in dental medicine

The pandemic context has put an even greater emphases on using the information technology in medical education. This creates safe environment for learning practical skills in clinical scenarios. My efforts will focus on:

- creation and implementation of an IT platform for assisted learning and computerized assessment based on the concept of virtual patient
- implementation of different information systems in dental education and practice like artificial intelligence, augmented reality, virtual reality, tele-dentistry.

Artificial intelligence (AI) has registered a series of advancements in the last 10 years and has now beginning to be in establishing diagnosis. I plan to identify AI based tools and technologies with application in dentistry and to introduce these tools in medical training and research activities.

2.2. INCREASING THE SCIENTIFIC REPUTATION OF THE DEPARTMENT / FACULTY / UNIVERSITY

2.2.1. Developing collaborations with research laboratories outside the faculty and creating a research laboratory by attracting funds through financed research projects

A considerable part of the published results has already been obtained by collaborating with various laboratories within the "Petru Poni" Institute of Macromolecular Chemistry, "Alexandru Ioan Cuza" University and "Gh. Asachi" Technical University. I will continue these collaborations and expand them, in order to make it possible to win projects (European funding) that can even finance the establishment of a new biomechanics' laboratory within our faculty.

I intend to facilitate knowledge exchanges and to expand collaborations with researchers from the country and abroad.

2.2.2. Use of research results through publishing of scientific papers

I intend to make a better usage of the performed studies (Fig. 127) by publishing in ISI-rated journals, with an important impact factor, and in journals indexed in international databases.

A second direction is that of participating with communications at prestigious international events, establishing new professional connections and collaborations with specialists from prestigious universities abroad. And, last but not least, the publication of books in internationally recognized publishing houses and in CNCSIS recognized national publishing houses, respectively.

2.2.3. Research activity and coordination of PhD candidates

Our discipline has an acute lack of teaching staff, with a coverage of 30% (9 out of 27). The main reason is lack of seats in the doctoral school. Again, it is my duty to identify students and resident doctors with consistent interest for long-time sustaining learning, for research in fixed prosthodontics and our discipline research topics and for an academic career. I will encourage and support them in reaching their goals, offering them constant guidance and help during their doctoral period.

I am aware of the responsibility and of the tremendous work the coordination of a PhD thesis requires. I had the opportunity of collaborating in multiple scientific studies for doctoral theses, from research designing to clinical and laboratory studies carried out, 3D and FEA analyses, data gathering and statistical analyses with result interpretations.

A close cooperation between PhD students and coordinator is mandatory for maintaining a high level of motivation and this starts with selecting the most captivating and feasible research topic, some of them previously mentioned in chapter II.2.1. (*Development of research directions*), designing the research protocol and finding the optimal scientific methods to support it. This entails the following:

- close interdisciplinary collaboration, establishing partnerships with specialists in other medical fields like microbiology, immunology, rheumatology, chemistry, but also informatics, biomechanics, bioengineering
- cooperation with other services and institutions in the country to carry out multidisciplinary projects and to support mobility of doctoral students.

This will make information and experience exchange possible, stimulating new research ideas and new technological solutions. The results will be materialized in papers published in ISI indexed journals with high impact factor.

3. FUTURE DIRECTIONS IN TEACHING ACTIVITY

The impact of a teaching figure can be constructive or destructive in the development of a young practitioner and this can put a lot of pressure on the teaching staff. The student profile is continuously changing and so are their expectations, as the exposure to other types of information is evolving. This requires a constant adaptation to their changing needs. We are living challenging times for education, during the COVID pandemic. Classical teaching methods, considered until recently obsolete by our students, prove now their real value, reclaiming their position among the tools of medical training. This is empowering us, the teachers, but also forces us to find the right balance between the classical and modern methods, like computer-assisted learning.

Recently we did a student survey about on-line learning and computer-assisted learning. The analysis of their needs and expectations indicated the necessity of a student-centered teaching and learning activities, adapted to their level of understanding, a stimulating management of the academic group, a motivating active-participatory strategy, a diversified evaluation with the change of the memorization-playback paradigm with tests focused on student's performance and on the obtained competences.

The nature of the clinical traineeship we carry out with the students allows a closer approach to them, a better knowledge of their needs and possibilities, so that teaching and, subsequently, evaluation methods can be adapted to bring real benefits to the educational process. In the particular case of the discipline of Fixed Prostheses, students have certain expectations related to clinical activity and direct interaction with the patient. An important factor is to ensure the favorable framework for carrying out practical work, this being the support on which a proper educational act can be built. Moreover, in disciplines with a deep practical character, such as fixed prosthodontics, it is fundamental that every student be trained in performing therapeutic maneuvers, both on the simulator and on real patients, in safe conditions and environment. As coordinator of didactic activity, it has become my responsibility to ensure the means and resources needed for a performant teaching activity. Beside my constant diligences at faculty and university level, my goal is to identify resources to improve the accessibility of students to modern technologies and materials.

Virtual Patient software applications are effective tools in expanding and diversifying training methods to improve clinical reasoning capacity. Within the internal research project, we created a series of simulated clinical cases in which we also requested the participation of students. The virtual patients had a positive, stimulating effect on their interest in a well-founded theoretical approach to clinical situations. I intend to continue these collaborations with students, but I also plan to expand the use of these education systems in other dental specialties, by co-opting colleagues from other disciplines and departments.

The continuous accumulation of knowledge must aim at their application and capitalization in practice. The gained experience allows the adaptation and improvement of some techniques and methods, both in the pedagogical and the dental practical sphere, making possible the development of some types of approaches and the introduction of new ones.

- adaptation of the educational act, according to the particularities of nationality and individuality of the students
- enhance editorial activity with the publication of course notes and practical activity textbooks on Single-unit dental restorations, Occlusology, Fixed prosthodontics, Ceramic

restorations and Dento-somato-facial esthetics, in native language but also in English and French

- sustaining presentations with examples, conclusive demonstrations, rich iconography and multi-media presentations
- logical argumentation must support the presentation, so that the student, in turn, can assimilate the notions in a logical way, learn to think medically and to form or practice their general and specific intellectual abilities in the field of dentistry
- promoting active-participatory, student-centered methods (student involvement in the teaching-learning process, solving hypothetical clinical situations, simulations, virtual patients, research projects, etc.) within the traineeship and outside it
- preparing the students to cope with professional stress
- development of objective tools for evaluating the activity and training of students, elaboration of assessment criteria based on the objectives proposed in the teaching-learning process, assuring the correct and impartial evaluation
- improving the educational offer with training that makes use of new tools like artificial intelligence, augmented reality, virtual reality, tele dentistry
- training in actions that allow trainees to develop interpersonal communication skills, so necessary in relation to patients and with each-other
- collaboration with other national centers to facilitate student mobility and to encourage students to participate in inter-institutional educational exchanges
- carrying out tutoring activities: meetings with students on learning issues, career guidance, social assistance, etc.

4. CORRELATION OF RESEARCH, EDUCATIONAL AND MEDICAL ACTIVITIES

I will try to approach the three directions of activity in a constructive and balanced way, trying to potentiate each direction through the other two. I have the following aspects in mind:

- optimization of existing curricula, in accordance with real possibilities and needs - introduction of virtual patients in the curriculum
- promoting innovations in the field of professional methodology and technology (new specialized laboratories, competence assessment systems, etc.)
- implementation of research results in medical practice or educational process (minimal invasive restorations, fiber-reinforced composite, PEEK, large-scale use of virtual patients, as a stage of transition to clinical maneuvers etc.)
- active involvement of students in research, educational and medical process (student participation in authoring virtual patients)
- coordinating student scientific papers and stimulating students to participate in scientific events
- coordination of diploma papers
- coordinating research topics within student scientific circles.

5. CONCLUSIONS

Most professional categories have the duty to improve in only one field. We are one of those categories that require improvement on several levels at the same time. This makes obtaining exceptional results all the more worthwhile.

To excel in all three directions is a difficult mission, which requires dedication, love of peers, on the one hand, as well as the ability to operate with theoretical notions and sometimes abstract elements, specific to the research activity, on the other hand.

The three areas are of major importance in the development of a nation. Despite this, in our country, they have been nonetheless neglected, our mission sometimes being a difficult one.

Through the objectives for the development of the university career, proposed in this plan, I am pursuing both a continuous process of professional and personal development and a contribution to the training of generations of specialists towards high human and professional quality.

SECTION III.
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