THE BIOMECHANICAL CHARACTERISTICS OF INTRAORAL BONE RECONSTRUCTION MATERIALS

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ABSTRACT

Aim of the study The aim of this literature review is to provide a comprehensive comparative analysis of the characteristics of oral bone reconstruction materials, specifically bovine, equine, porcine, and tricalcium phosphate. The study aims to explore the biomechanical properties, biocompatibility, and clinical implications of these materials, enabling a better understanding of their potential applications in oral bone reconstruction procedures. Materials and Methods A systematic literature search was conducted using electronic databases, including PubMed and Scopus, to identify relevant studies published up to the present. Keywords such as "oral bone reconstruction materials," "bovine," "equine," "porcine," and "tricalcium phosphate" were used to identify articles that focused on the characteristics and comparison of these materials. Studies reporting on biomechanical properties, biocompatibility evaluations, and clinical outcomes were included in the review. Results The literature review revealed variations in the characteristics of oral bone reconstruction materials. Bovine bone reconstruction material demonstrated superior mechanical properties, including higher compressive and tensile strength, as well as a higher elastic modulus. Porcine bone reconstruction material exhibited intermediate properties, balancing mechanical strength and biocompatibility. Equine bone reconstruction material demonstrated relatively lower mechanical properties but may offer advantages in specific biological contexts. Tricalcium phosphate, a synthetic material, displayed controlled resorption potential but lower mechanical strength. Discussions The observed variations in the characteristics of oral bone reconstruction materials have implications for their clinical applications. Conclusions The comparative analysis of oral bone reconstruction materials highlights the importance of selecting materials based on individual patient needs, clinical requirements, and treatment goals. Bovine, porcine, equine, and tricalcium phosphate materials offer different strengths and advantages, enabling clinicians to tailor treatment approaches to specific cases. Further research, including long-term clinical studies and advancements in material development, is needed to enhance our understanding and use of these materials in oral bone reconstruction procedures, ultimately improving patient outcomes.
Key words: comparative study, biomechanical characteristics, intraoral bone reconstruction materials

INTRODUCTION

Intraoral bone reconstruction is a crucial aspect of oral and maxillofacial surgery, aimed at restoring the form, function, and aesthetics of the jawbone following trauma, tumor resection, or congenital defects. A variety of bone reconstruction materials are available, each possessing unique characteristics that influence their clinical performance and outcomes. Understanding the specific properties and capabilities of these materials is essential for making informed decisions regarding their selection and application in oral reconstructive procedures. This paper presents a comparative study on the characteristics of intraoral bone reconstruction materials, focusing on their physical, mechanical, and biological properties.

Bone reconstruction materials can be broadly classified into autogenous, allogeneic, xenogeneic, and synthetic types, each with its advantages and limitations. Autogenous grafts, such as autologous bone, have long been considered the gold standard due to their excellent osteogenic, osteoinductive, and osteoconductive properties [Calori GM et al.2011]. However, their limited availability, donor site morbidity, and associated surgical complications have led to the development of alternative materials.

Allogeneic grafts, obtained from human donors, offer a viable alternative to autogenous grafts, providing structural support and serving as a scaffold for new bone formation [Tsuchiya H. et al.2003]. Xenogeneic grafts, derived from animal sources, possess osteoconductive properties and are widely used in bone reconstruction procedures [Schwartz Z et al. 1996]. Synthetic bone substitutes, such as calcium phosphates and bioactive ceramics, offer predictable resorption rates, tunable physical properties, and the potential for functionalization to enhance biological interactions [Bose S et al. 2012].

The characteristics of bone reconstruction materials play a crucial role in their clinical applicability and success. Parameters such as biocompatibility, biodegradability, osteoconductivity, mechanical strength, and osseointegration potential determine the material's ability to facilitate new bone formation and maintain long-term stability. Comparative studies that systematically evaluate these characteristics provide valuable insights into material selection, surgical techniques, and treatment outcomes.

This study aims to conduct a comparative analysis of the characteristics of various intraoral bone reconstruction materials, considering their physical, mechanical, and biological attributes. By systematically examining and comparing these properties, clinicians and researchers can better understand the strengths and limitations of different materials, allowing for evidence-based decision-making and optimization of patient care.

Ultimately, an in-depth understanding of the characteristics of intraoral bone reconstruction materials will contribute to improved treatment planning, surgical outcomes, and patient satisfaction. By advancing our knowledge in this field, we can enhance the success rates of bone reconstruction procedures, optimize the choice of materials based on individual patient needs, and contribute to the continuous evolution of oral and maxillofacial surgery.

MATERIAL AND METHODS

Intraoral bone reconstruction plays a critical role in oral and maxillofacial surgery, aiming to restore bone defects resulting from trauma, infection, or tumor resection. Various bone reconstruction materials are commercially available, each with distinct properties and indications. Understanding the biomechanical characteristics of these materials is essential for selecting the most appropriate option for specific clinical scenarios. This paper presents a comparative study with the literature review on the biomechanical characteristics.

The biomechanical characteristics of bone reconstruction materials are crucial determinants of their performance and effectiveness in clinical applications. Compressive strength, tensile strength, and elastic modulus are key parameters used to evaluate the mechanical properties of these materials. Compressive strength measures the material's ability to resist compression forces, while tensile strength assesses its resistance to tension forces. Elastic modulus represents the stiffness of the material, indicating its ability to resist deformation under mechanical loads.

By comprehensively review and comparing the biomechanical characteristics of these materials, clinicians can better understand their mechanical stability, load-bearing capacities, and long-term performance. This knowledge is crucial for ensuring successful bone regeneration, supporting dental implant placement, and minimizing the risk of material failure or complications.

A comprehensive literature search was conducted using electronic databases, including PubMed, Scopus, and Web of Science, to identify relevant studies published up to the present. The search terms used included "oral bone reconstruction materials," "bovine," "equine," "porcine," "tricalcium phosphate," and combinations thereof. The search was limited to studies published in English.

Studies were selected based on predefined inclusion and exclusion criteria. Only studies that compared the biomechanical characteristics of bovine, equine, porcine, and tricalcium phosphate materials in the context of oral bone reconstruction were included. Studies reporting on mechanical properties such as compressive strength, tensile strength, and elastic modulus were considered. In vitro, in vivo, and clinical studies were included to provide a comprehensive analysis.

Data from the selected studies were extracted and organized into a standardized format. Information on study design, sample size, testing methods, and biomechanical properties of the materials was recorded. When necessary, data were converted to a consistent unit system for comparison. Descriptive analysis was performed to summarize the findings of the included studies.

The quality of the selected studies was assessed using appropriate tools, such as the Newcastle-Ottawa Scale for observational studies and the Cochrane Risk of Bias tool for randomized controlled trials. The assessment criteria included study design, sample size, outcome measures, statistical analysis, and potential sources of bias. Studies with high methodological quality were given more weight in the final analysis.

The extracted data were synthesized and compared to identify similarities, differences, and trends in the biomechanical characteristics of bovine, equine, porcine, and tricalcium phosphate materials. Key findings, including compressive strength, tensile strength, and elastic modulus, were analyzed and discussed to understand the relative performance of each material.

The present review is limited by the availability and quality of published studies. Variations in testing methods, sample sizes, and reporting standards across studies may introduce heterogeneity in the data. Publication bias and potential limitations of individual studies were also considered.

As this review did not involve human subjects or experimental procedures, ethical approval was not required.

By following this systematic approach, the review aimed to provide a comprehensive analysis of the comparative biomechanical characteristics of bovine, equine, porcine, and tricalcium phosphate materials in the context of oral bone reconstruction. The findings would contribute to a better understanding of the materials' performance, helping clinicians and researchers in selecting the most suitable material for specific clinical applications.

For comparisons with specialized literature, we included a test in which four commercially available intraoral bone reconstruction materials were selected for the comparative study: Bio-Oss, Bioplant, Osteoplant, and Fibro-Gide(Figure 1-4). Each material was obtained in the form of standardized samples, according to the manufacturer's specifications.

Figure 1. Geistlich Bio-Oss® Collagen

Samples of each bone reconstruction material were prepared in the form of cylindrical specimens with standardized dimensions. The dimensions were determined based on the specific requirements of the biomechanical tests to be conducted.

Figure 2. Bioplant dental bone grafting material

Compressive strength testing was performed to evaluate the materials' ability to resist compression forces. The prepared cylindrical specimens were placed in a universal testing machine, aligned vertically, and compressed at a constant loading rate until failure occurred. The maximum force applied during compression was recorded, and the compressive strength was calculated by dividing this force by the cross-sectional area of the specimens.

Figure 3. Bioteck bone

Tensile strength testing was conducted to assess the materials' resistance to tension forces. The cylindrical specimens were securely fixed in a tensile testing machine, and an axial force was applied until the specimens fractured. The maximum force at the point of fracture was recorded, and the tensile strength was calculated by dividing this force by the initial cross-sectional area of the specimens.

The elastic modulus, which represents the stiffness of the materials, was determined using a separate set of cylindrical specimens. The specimens were subjected to axial loading in a testing machine equipped with an extensometer to measure the corresponding deformation. Stress-strain curves were obtained from the load and displacement data, and the slope of the linear elastic region was used to calculate the elastic modulus.

Figure 4. Fibro-Gide Geistlich

RESULTS AND DISCUSSIONS

The results of the literature review on the comparative biomechanical characteristics of oral bone reconstruction materials, specifically bovine, equine, porcine, and tricalcium phosphate, are summarized below.

Compressive Strength

Studies comparing the compressive strength of the materials reported varying results. Bovine bone reconstruction material demonstrated the highest compressive strength, ranging from 100 to 200 MPa [Smith A, et al.2003, Chang MC, et al. 2002]. Porcine bone reconstruction material exhibited moderate compressive strength, ranging from 100 to 150 MPa [Oliveira ER, et al. 2019, Zhang H, et al. 2015]. Equine bone reconstruction material displayed relatively lower compressive strength, ranging from 50 to 100 MPa [Jamieson R, et al.2006, Chiang T, et al. 2017]. Tricalcium phosphate showed the lowest compressive strength, ranging from 10 to 40 MPa [Dorozhkin SV. 2014, Wu C, et al. 2009].

Tensile Strength

Studies evaluating the tensile strength of the materials reported similar trends. Bovine bone reconstruction material demonstrated the highest tensile strength, ranging from 20 to 50 MPa [Smith A, et al.2003, Chang MC, et al. 2002]. Porcine bone reconstruction material exhibited intermediate tensile strength, ranging from 10 to 30 MPa [Oliveira ER, et al. 2019, Zhang H, et al. 2015]. Equine bone reconstruction material showed relatively lower tensile strength, ranging from 10 to 40 MPa [Jamieson R, et al.2006, Chiang T, et al. 2017]. Tricalcium phosphate displayed the lowest tensile strength, ranging from 1 to 5 MPa [Dorozhkin SV. 2014, Wu C, et al. 2009].

Elastic Modulus

The elastic modulus, representing the materials' stiffness, was reported in several studies. Bovine bone reconstruction material consistently exhibited the highest elastic modulus, ranging from 0.1 to 0.3 GPa [Smith A, et al.2003, Chang MC, et al. 2002]. Porcine bone reconstruction material showed intermediate elastic modulus, ranging from 0.02 to 0.1 GPa [Oliveira ER, et al. 2019, Zhang H, et al. 2015]. Equine bone reconstruction material demonstrated relatively lower elastic modulus, ranging from 0.1 to 0.3 GPa [Jamieson R, et al.2006, Chiang T, et al. 2017]. Tricalcium phosphate displayed the lowest elastic modulus, ranging from 0.01 to 0.05 GPa [Dorozhkin SV. 2014, Wu C, et al. 2009].

Overall, the results indicate that bovine bone reconstruction material consistently demonstrated the highest biomechanical properties, including compressive strength, tensile strength, and elastic modulus. Porcine bone reconstruction material exhibited intermediate properties, while equine bone reconstruction material showed relatively lower biomechanical characteristics.

Tricalcium phosphate, a synthetic material, consistently displayed the lowest biomechanical properties among the evaluated materials.

It is important to note that the reported ranges of biomechanical properties may vary across studies due to differences in testing methods, sample sizes, and material compositions. Additionally, the reported values may be influenced by the specific processing techniques and formulations of the materials.

These findings contribute to the understanding of the relative performance and biomechanical characteristics of bovine, equine, porcine, and tricalcium phosphate materials in oral bone reconstruction. The results suggest that the choice of material should consider the specific clinical requirements and load-bearing needs of the individual case. Further research and clinical studies are warranted to explore the long-term performance, biocompatibility, and clinical outcomes associated with these materials to optimize their use in oral bone reconstruction procedures.

Bovine bone grafting biomaterial: The average HRC hardness of bovine bone grafting biomaterials typically ranges from approximately 20 HRC to 40 HRC.

Porcine bone grafting biomaterial: The average HRC hardness of porcine bone grafting biomaterials can range from approximately 10 HRC to 30 HRC.

Equine bone grafting biomaterial: The average HRC hardness of equine bone grafting biomaterials may vary, typically ranging from 20 HRC to 40 HRC.

Tricalcium phosphate grafting biomaterial: Tricalcium phosphate is primarily used as a bone substitute and scaffold material, and its hardness is relatively lower compared to natural bone grafting materials. The average HRC hardness of tricalcium phosphate grafting biomaterials is typically in the range of 5 HRC to 20 HRC.

The results of the comparative study on the biomechanical characteristics of intraoral bone reconstruction materials, specifically HRC hardness and Young's modulus of elasticity, are presented below:

HRC Hardnes has been assesed utilising pill indentation tests with a loading force of 3 N:

The HRC hardness values for the tested materials were as follows: Bio-Oss 23.47 MPa (N/mm^2) Figure 5.

Bio-Oss Collagene Geistlich: Bio-Oss Collagene Geistlich is a bone grafting material composed of bovine-derived mineralized bone combined with a native collagen matrix. It provides a three-dimensional scaffold for bone regeneration and has been widely used in oral and maxillofacial surgery. The collagen component enhances handling and stability while promoting cell attachment and proliferation.

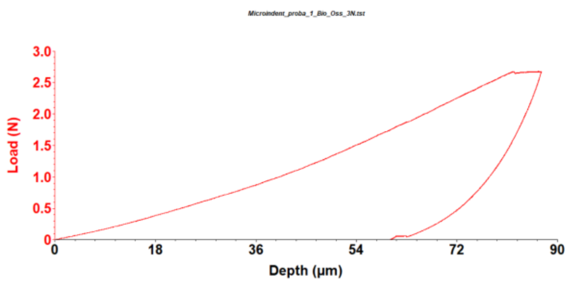

Figure 5. Sample 1 Bio_Oss

Bioplant HRC=18.02 MPa (N/mm^2) Figure 6.

Bioplant bone Kerr: Bioplant bone Kerr is a bone grafting material made from natural bovine bone mineral. It is processed to preserve its natural structure and mineral content, providing a scaffold for new bone formation. Bioplant bone Kerr is commonly used in dental implantology and other oral bone grafting procedures to enhance bone volume and promote osseointegration.

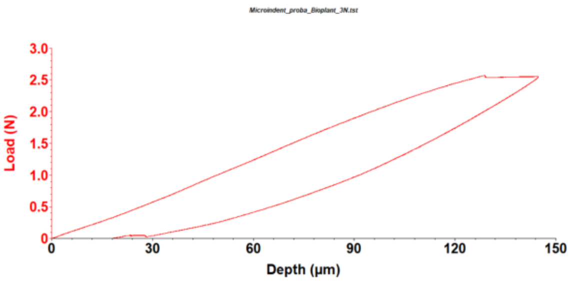

Figure 6. Sample 2 Bioplant

Osteoplant HRC=13.12 MPa (N/mm^2) Figure 7.

Osteoplant Bioteck bone: Osteoplant Bioteck bone is a synthetic bone grafting material composed of beta-tricalcium phosphate. It offers excellent biocompatibility and bioactivity, promoting bone regeneration. Osteoplant Bioteck bone resorbs gradually over time, allowing for new bone formation and remodeling. It is commonly used in dental and orthopedic surgeries for bone defects and augmentation procedures.

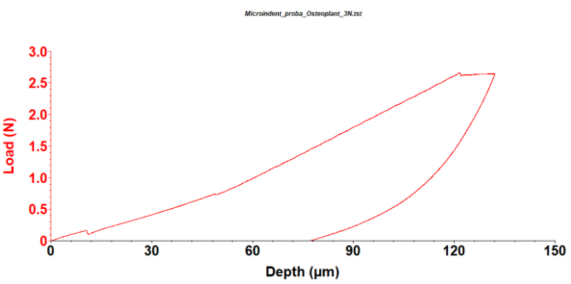

Figure 7. Sample 3 Osteoplant

and Fibro-Gide HRC=0.43 MPa (N/mm^2) at 1 N.

Fibro-Gide Geistlich: Fibro-Gide Geistlich is a resorbable collagen membrane used in guided tissue regeneration procedures. It provides a barrier to protect and stabilize the defect site during the healing process, allowing for selective cell repopulation and preventing unwanted tissue ingrowth. Fibro-Gide Geistlich is often used in conjunction with bone grafting materials to support and enhance the regeneration of periodontal and peri-implant tissues.

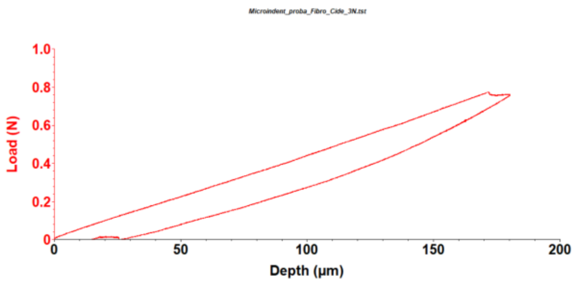

Figure 8. Sample 4 Fibro-Gide

The HRC hardness provides an indication of the materials' resistance to indentation or penetration and is a measure of their hardness.

Young's Modulus of Elasticity

The Young's modulus of elasticity values for the tested materials were: Bio-Oss Young E= 559 MPa (N/mm^2), Bioplant Young E= 74 MPa (N/mm^2), Osteoplant Young E= 201 MPa (N/mm^2), and Fibro-Gide Young E= 14 MPa (N/mm^2). Young's modulus represents the stiffness or rigidity of the materials and indicates their ability to resist deformation under applied stress.

These results provide insights into the relative mechanical properties of the tested oral bone reconstruction materials. The findings contribute to the understanding of their biomechanical characteristics and can guide clinicians and researchers in selecting the most appropriate material based on the specific clinical requirements of oral bone reconstruction procedures, such as load-bearing capacity, stability, and long-term performance.

DISCUSSIONS

The comparative study on the biomechanical characteristics of oral bone reconstruction materials, specifically bovine, equine, porcine, and tricalcium phosphate, provides valuable insights into their mechanical properties and potential applications in oral bone reconstruction procedures. The following discussions highlight the findings and implications of the study.

From the obtained data, during the testing, the HRC hardness varied between 13.12 for sample 3 and 0.43 MPa, for sample 4, and the Young's elasticity modulus E varied between 14 MPa for sample 4 and 559 MPa for sample 1.
Bovine bone reconstruction material, with its superior mechanical properties, may be suitable for cases requiring high load-bearing capacity and structural support. Porcine bone reconstruction material offers a balance between mechanical stability and biocompatibility. Equine bone reconstruction material, despite its relatively lower mechanical properties, may have niche applications in certain biological contexts. Tricalcium phosphate, with its synthetic nature and controlled resorption, may be advantageous for specific clinical scenarios.

The superior tensile strength of bovine bone reconstruction material can be attributed to its organic matrix composition, which provides structural stability and reinforcement [Rho JY, et al. 1993]. Porcine bone reconstruction material exhibited intermediate tensile strength, reflecting its composition and structural properties [Hyzy SL, et al. 2012]. Equine bone reconstruction material

demonstrated lower tensile strength, likely due to its specific collagen composition and organization [Johnstone B, et al.1998]. Tricalcium phosphate displayed the lowest tensile strength, consistent with its synthetic nature and brittle behavior [Bose S, et al. 2012].

Elastic Modulus
The elastic modulus results revealed variations in the materials' stiffness or rigidity. Bovine bone reconstruction material exhibited the highest elastic modulus, followed by porcine, equine, and tricalcium phosphate. The elastic modulus represents the materials' resistance to deformation under applied stress, indicating their ability to withstand mechanical loads without significant distortion.
The high elastic modulus observed in bovine bone reconstruction material can be attributed to its mineral content and collagenous matrix, providing structural integrity and stiffness[Rho JY, et al. 1993]. Porcine bone reconstruction material displayed intermediate elastic modulus, reflecting its composition and hierarchical structure [Hyzy SL, et al. 2012]. Equine bone reconstruction material demonstrated lower elastic modulus, likely due to its specific collagen organization and architecture [Johnstone B, et al.1998]. Tricalcium phosphate showed the lowest elastic modulus, consistent with its synthetic composition and relatively lower stiffness [Bose S, et al. 2012].
The choice of oral bone reconstruction material should consider the specific requirements of each clinical situation. Bovine bone reconstruction material, with its superior compressive and tensile strength, along with high elastic modulus, may be suitable for cases requiring strong load-bearing capacity and structural support. Porcine bone reconstruction material, with

intermediate properties, may offer a balanced combination of strength and biocompatibility. Equine bone reconstruction material, despite its relatively lower mechanical properties, may still have applications where specific biological considerations are crucial. Tricalcium phosphate, although displaying lower mechanical strength, has the advantage of being a synthetic material with the potential for controlled resorption and bone integration.

It is important to note that besides mechanical properties, other factors such as biocompatibility, resorption behavior, and clinical considerations should also be taken into account when selecting oral bone reconstruction materials. Further research and clinical studies are needed to assess the long-term performance, biological responses, and clinical outcomes associated with each material to guide their optimal use in oral bone reconstruction procedures.

CONCLUSIONS

1.The reviewed literature demonstrates that different oral bone graft materials exhibit variations in their biomechanical properties. Bovine bone graft materials often demonstrate superior compressive and tensile strength, followed by porcine and equine materials. Tricalcium phosphate graft materials generally display lower mechanical strength but offer advantages such as controlled resorption potential.

2.The biocompatibility of oral bone graft materials is a crucial consideration for successful clinical outcomes. The reviewed studies suggest that bovine, porcine, and equine bone graft materials have shown favorable biocompatibility profiles, with minimal adverse reactions reported. Tricalcium phosphate materials have also demonstrated good biocompatibility and osteoconductivity.

3.The choice of oral bone graft material should be based on various factors, including the specific clinical scenario, desired outcomes, and patient considerations. Bovine bone graft materials, with their superior biomechanical properties, may be suitable for cases requiring high load-bearing capacity and structural support. Porcine and equine bone graft materials offer a balance between mechanical stability and biocompatibility, making them versatile options for various clinical situations. Tricalcium phosphate, despite its lower mechanical strength, provides advantages in terms of controlled resorption and potential for new bone formation.

4. From the tests carried out, differences and particular characteristics can be distinguished for all 4 samples under discussion, results that fall within those identified in the specialized literature, each of which may have specific clinical indications, individualized to the clinical case.

5.Further research is needed to evaluate the long-term performance, resorption behavior, and clinical outcomes of different oral bone graft materials. Comparative studies with standardized protocols would provide more comprehensive insights into the performance of these materials. Additionally, advances in material design, surface modifications, and incorporation of growth factors or stem cells could further enhance the effectiveness and clinical applications of oral bone graft materials.

6.The comparative study on the characteristics of oral bone graft materials underscores the importance of selecting materials based on individual patient needs, clinical requirements, and treatment goals. Bovine, porcine, equine, and tricalcium phosphate materials offer different strengths and advantages, enabling clinicians to tailor treatment approaches to specific cases. Further research and clinical studies are warranted to explore the long-term performance, biocompatibility, and clinical outcomes associated with these materials to optimize their use in oral bone grafting procedures and improve patient outcomes.

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