DOSE REDUCTION STRATEGIES IN COMPUTED TOMOGRAPHY OF CRANIO-FACIAL TRAUMA

DOCTORATE THESIS SUMMARY

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Iaşi
2015
THEORETICAL FACTS

Even if it is a general consensus that computed tomography (CT) is one of the best imaging diagnostic tools, especially in emergency departments, a great concern has been raised in the last decade regarding the potentially increased risk of developing cancer (Brenner D. et al., 2001; Donnelly L et al., 2001; Haaga JR., 2001; Nickoloff EL. et al., 2001). When CT was first introduced in the early ‘70s (Beckmann E.C., 2005), the most important issue of this new technique was that it delivered a high dose compared with the other X-ray methods, but this fact was quickly overcome by clinical justification, especially in malignant pathology where the overall radiation dose was less concern. In 1989, despite comprising only 2% of all examinations, CT contributed around 20% of the collective dose to the population from diagnostic imaging (Shrimpton et al., 1991). Today the circumstances have changed: the CT became faster and widely used (Smith-Bindman R. et al., 2009), but unfortunately more and more also in benign and pediatric pathology, sometimes without appropriate justification. In USA, it is claimed that CT dose count for almost 67% of the total dose from medical diagnostic sources (Mettler F.A. et al., 2000); 67 millions CT exams were performed in 2006 (Brenner DJ, Hall EJ, 2007), thirty time more than in 1980 (National Council on Radiation Protection and Measurements, 2009).
**Computed Tomography Dose Index (CTDI)** – it is the primary concept of dose measurement and it represents the average radiation dose for a CT slice (Kalender W.A., 2014); it can be quantified by using measurements in acrylic phantoms (usually 16 and 32 mm phantoms).

**Reduction and management of the CT radiation dose**

The main parameters that influence the level of radiation dose for the same scan volume are summarized in the Figure 1.

![Flowchart showing Usual methods for dose reduction in CT](chart)

**Fig. 1** Usual methods for dose reduction in CT.

*The Tube Current (mA) and Rotation Time* - Patient dose is directly proportional to the tube current, so, if we increase the mA by 50%, the patient dose will also increase by 50%. The same can be said for a single rotation time (decreasing the rotation time by half, the radiation dose will also be decreased by half). Their product is the mAs and is reported by almost all CT manufacturers.

*The kilovoltage (kV)* - Another method to reduce the dose is by modifying the kV; this will impact both the quantity and quality of emitted X-rays. The relationship between dose and kV is not linear; for example, lowering
the kV from 140 to 120 (about 17%) will produce a 30% dose reduction. *The pitch* - Pitch is the table feed during one complete tube rotation divided by the collimated width of the X-ray beam. By increasing the pitch with a fixed scan length the radiation dose is reduced due to the lower total exposure time. For example, increasing pitch from 1 to 1.5 will reduce the radiation dose with 33%.

Unfortunately, reducing the dose of radiation will have an adverse effect on image quality. That is why the guiding principle of dose reduction has to be based on the concept of ALARA: As Low As Reasonably Achievable. Consideration must always be given to minimizing the radiation dose to the patient while preserving the necessary quality of diagnostic images.

**Cone Beam CT**

The computed tomography using a cone beam (CBCT) has begun to emerge as a great tool of diagnosing the head and neck trauma. This method is great in producing high spatial resolution and high bone details with a reduced radiation level compared with conventional CT scan.

First conventional CT scanner was introduced by Sir Godfrey N. Hounsfield in 1967. Data acquisition in conventional CT imaging has evolved through 4 generations of acquisition geometries. First-generation scanners used parallel pencil beams of x-rays and required both translation and rotation of the source and a single-detector apparatus. Second-generation scanners introduced fan-beam x-ray geometry and used a single-detector linear array. In third-generation scanners, the
single-detector arc was introduced in conjunction with fan-beam x-ray geometry. Fourth-generation scanners used a fan-beam of x-rays and a circular detector array. In current practice, multidetector helical CT (MDCT) scanning is most frequently used, answering the call for reduced acquisition times. MDCT is loosely based on third-generation geometry, though the detector array has multiple rows of detectors. (1)

In CBCT systems, the x-ray beam forms a conical geometry between the source (apex) and the detector (base). This is in contrast to conventional fan-beam geometry, in which the collimator restricts the x-ray beam to approximately 2D geometry. In a fan-beam single-detector arc geometry, data acquisition requires both rotation and z-direction translation of the gantry to eventually construct an image set composed of multiple axial sections.

The use of CBCT technology in clinical practice provides a number of potential advantages for maxillofacial imaging compared with conventional CT:

- Reducing the size of the irradiated area by collimation of the primary x-ray beam to the area of interest minimizes the radiation dose. Most CBCT units can be adjusted to scan small regions for specific diagnostic tasks;

- The volumetric data set comprises a 3D block of smaller cuboid structures, known as voxels, each representing a specific degree of x-ray absorption. The size of these voxels determines the resolution of the image. CT voxel surfaces can be as small as 0.625 mm square but CBCT units provide voxel resolution that are isotropic-equal in all 3 dimensions. This produces
submillimetre resolution ranging from 0.4mm to as low as 0.125 mm.

- CBCT acquires all basis images in a single rotation, scan time is rapid (10–70 seconds) and comparable with that of medical spiral MDCT systems.

One of the most important issues regarding the multiplanar capability of CBCT is understanding and correctly recognizing the anatomy, especially in reformatting views such as coronal or sagittal planes. There is also the possibility to recreate images in curved or flat plans in order to meet the diagnostician requirement and in order to maximize the imaging capability, but this add a degree of complexity for people not familiarly with the anatomy landmarks of multiplanar imaging.

![CBCT axial, coronal, and sagittal planes](image)

**Fig. 2** CBCT axial, coronal, and sagittal planes.
Chapter 10

Orbital trauma: from anatomy to imaging patterns – at standard and low-dose protocols

Trauma to the eye is the cause of blindness in more than half a million people worldwide and of partial loss of sight in many more, and it is often the main cause of unilateral loss of vision in developing countries. For example, in the United States orbital trauma occurs in approximately 3% of all emergency department visits.

Orbital injuries are often seen in patients with multiple traumas from traffic accidents, assault, falls from height, gunshot.

A basic knowledge of the potential injuries to the eye and of the anatomy of this region is necessary to determine the gravity and the extent of traumatic injury.

**Imaging Options**

Computed tomography (CT) is the method of choice for evaluating orbital trauma and it is useful for evaluating bone fractures, soft tissue injury and foreign body detection. CT is a fast method to perform, readily available, no special need for patient preparation, the eye movement do not degrade the image acquisition and has no risk if metallic fragment are suspected. CT has been shown to be more accurate than radiography in detecting fractures. When fractures are present, three-dimensional reformation is a useful tool to guide treatment.
Other methods may be useful for evaluating orbital trauma: radiography has a sensitivity of 64%–78% for a fracture, but it has very low sensitivity for soft-tissue injuries; ultrasonography (US) is very useful for evaluating the globe and its contents; but US is contraindicated if a ruptured globe is suspected and additionally is operator dependent and offers no information about bony trauma; magnetic resonance (MR) imaging may be difficult to perform and it is contraindicated if there is a possibility that a metallic fragment is present.

**MATERIALS AND METHODS**

The study is a retrospective analysis of 297 patients diagnosed as having head trauma hospitalized between 2009 and 2010 at “Prof. Dr. Nicolae Oblu” Hospital, Iasi. The patients were submitted to spiral CT scanning, and CT images were interpreted using the following protocols: axial, multiplanar reconstruction (MPR), 3D images and association of axial/MPR/3D images.

We evaluated the anatomical sites of lesions, dividing them according to the orbital walls: lateral; medial; superior (roof) and inferior (anterior, medial).

The orbit is a pyramidal space formed by seven bones: Frontal, Zygomatic, Maxillary, Ethmoidal, Sphenoid, Lacrimal, Palatine. The paired orbital cavities lie on each side of the midsagittal plane of the skull on close relation to the nasal sinus and cranial cavities. The volume of each adult orbit is about 30 cc. The orbital entrance averages about 35 mm in height and 45 mm in width. In adults, the depth of the orbit varies from 40 to 45 mm from the orbital entrance to the apex.
The medial wall - is approximately rectangular and it is formed by 4 bones: the frontal process of the maxilla (that forms the medial orbital rim), the lacrimal bone, the orbital plate of the ethmoid, and the lesser wing of the sphenoid.
At its anterior aspect, it contains the lacrimal fossa which is bounded by the anterior and posterior lacrimal crests. The lacrimal sac is intimately related to the medial canthal tendon, which is a major supporting structure of the superficial tissues of the medial orbital region. The vast majority of the medial wall is comprised of the lamina papyracea, a paperthin bone overlying the ethmoid sinus that facilitates the infection spread in cases of ethmoid sinusitis, into the orbit; it is extremely thin, varying from 0.2 to 0.4 mm in thickness.

The most posterior part of the medial wall is formed by the thick bone of the sphenoid body, adjoining the optic canal. The medial wall articulates with the roof at the fronto-ethmoid suture and it articulates with the floor at the maxillo-ethmoid suture. The lamina papyracea fractures easily in blunt orbital trauma and in the course of ethmoid sinus surgery, exposing the orbit to the risk of inadvertent surgical injury. Medial orbital wall trauma is strongly related with diplopia due to the mechanical entrapment of the medial rectus muscle (recognized on CT by displacement of the muscle into the fracture site, with or without bone displacement). CT scan also localizes the fragments of the fractured lamina papyracea even if the orbital sinus adjacent to the fracture is opacified. A degree of medial displacement of the lamina papyracea can be present, and the ethmoidal sinuses often are hyperdense due to edema and blood accumulation.

**The orbital floor** - is formed mainly by the orbital plate of the maxilla and with contributions from the zygoma anterolaterally and the palatine bone at its most posterior limit. The orbital floor is the roof of the maxillary sinus. In its posterolateral two-thirds, the floor is separated from the lateral wall by the inferior orbital fissure through
which the maxillary division of the trigeminal nerve enters the orbit.

An important structure is represented by the infraorbital groove which is the location of infraorbital nerve that supplies sensation to check and ipsilateral upper alveolus and teeth. Medial to the infraorbital nerve, the orbital floor is relatively thin and fractures easily.

Orbital floor fractures can occur isolated, but they are also associated with Le Fort II fractures (orbital floor fractures) and NOE fractures (medial orbital wall fractures). Orbital floor fractures may result when a object, which is of equal or greater diameter than the orbital aperture, hits the eye, and the resultant force is transmitted throughout the orbit causing a fracture of the orbital floor.
The imaging study of choice is CT scan, with axial and coronal reconstruction (thin cuts - 2-3 mm - with specific attention to the orbital floor and optic canal).

**The lateral wall** - is the thickest of the orbital walls and is formed by the greater wing of sphenoid posteriorly and the zygoma anteriorly. It is separated from the floor by the inferior orbital fissure and from the roof by the superior orbital fissure (posteriorly) and the frontosphenoid suture.

**The orbital roof** - is formed by the frontal bone with a minimal contribution from the lesser wing of sphenoid. It forms the floor of the anterior cranial fossa. The orbital roof is strong and rarely fractures. The lacrimal gland is located in a fossa in the anterolateral aspect of the roof. Isolated fractures of the orbital roof are uncommonly seen in the absence of a fracture of the superior orbital rim.

**CONCLUSIONS**

Facial traumatized patients with clinical suspicion of orbital injuries are usually first evaluated with spiral CT, the best protocol is to obtain thin-section (1-3 mm) axial CT scans and then performing multiplanar reformation (specially coronal reformation is very useful). Knowledge of diverse imaging patterns of potential injuries is essential to make a fast and accurate diagnosis of post-traumatic orbital injury.
We analyzed in our study the most important dose-reduction strategies. In the practical experiment we evaluated only two methods based on current modulation: lowering the Tube Current x Rotation Time product (mAs) and the kilovoltage (kV). In a recent study, Mullins et al concluded that although the low-dose images were moderately noisier they may be acceptable for a safe diagnostic, especially for use in younger patient or those who will undergo serial scans over a short time follow-up (Mullins ME et al., 2004). Similar conclusions were achieved in another study by Britten et al. (Britten AJ et al., 2004). Some of the limitations of the both studies were the small population cohorts (20 and 23 patients) and the generality because the cohorts were picked based on age criteria (older than 65 years). Regarding this issues, we design our study using a larger cohort (51 patients) and no age limitations.

MATERIALS AND METHODS

The purpose of this study was to validate the feasibility of using low-dose CT protocols for cranio-facial trauma. Our hypothesis was that we can use protocols that
reduce with 30-50% the radiation dose while maintaining a good diagnostic level.

**Patients population** - The study was made in the Radiology department of the Emergency Hospital "Prof. Dr. N. Oblu", Iasi. We retrospectively analyzed the patients database between June 2013 and May 2014. From 4513 patients who undergo head CT for traumatic cranio-facial injury, we only enrolled 51 patients that respect the inclusion criteria: more than two scan in the same hospitalization interval and one of the scan has to be with low dose protocol. Our study design had our institutional review board and ethics committee approval; the written informed consent was not needed because the studies were clinically indicated and were performed with a low-radiation dose protocol.

**CT parameters** - In our department we use a 16-section CT machine (Toshiba Aquilion) and a standard head-protocol with the following parameters: 250 mA, 1 second rotation time and 130 kV that will deliver a CTDI\textsubscript{vol} of 53 mGycm. We also have two predefined low-dose protocols: 250 mA, 0.5 sec rotation time and 130 kV, and another one with 250 mA, 0.75 sec rotation time and 110 kV – those will deliver 28 and respectively 34 mGycm, so a 50% and respectively 34% dose-reduction. All data included in this study were reconstructed in brain-window (width 80 HU (Hounsfield unit), level 40 HU) with an axial section of 3 mm.

**Evaluation of resulting images** - Two neuroradiologists (MD1 with 10 years of experience and MD2 with 12 years of experience) evaluated the 102 non-enhanced CT scans (two different scans for each patient,
one of them with low-dose protocol), randomly selected. The readers were blinded to all clinical data and scans parameters. For each scan set they were asked to assess the overall image quality focusing on typical aspects of a brain image quality: gray matter – white matter conspicuity, subarachnoid space and ventricular margins sharpness, image noise; they were asked to use a subjective 4-point scale: score 4 = good quality, score 3 = acceptable, score 2 = poor quality (for this score, they also have to appreciate if the images are diagnostic or non-diagnostic), and score 1 = non-diagnostic image quality; the readers were also instructed to give another score when the readers consider. Finally, 51 sets of direct-paired (standard dose and low-dose) images were prepared, covering the following anatomic areas: basal ganglia, corona radiata, centrum semiovale and posterior fossa; the radiologists performed pair-wise comparison in blinded manner between standard and low-dose images, rating as having image quality better than, equal to, less then and significantly less than the other images in the pair.

**Statistic analysis** - We measured the inter-rater agreement by calculating Cohen kappa statistics. A very good agreement was defined for k value > 0.80, good for k between 0.6 – 0.8, moderate for k between 0.4 – 0.6, fair for k between 0.2 – 0.4 and poor or no agreement for k less than 0.2. Statistical significance was established at a p value below .05. Statistical analysis was performed using SPSS (IBM SPSS Statistics, release 20.0.0 for Windows).

**RESULTS**
When the readers evaluated the standard-dose images, they scored as good quality approximately 65% of cases (66.7 % reader MD1 and 64 % reader MD2), as
acceptable quality 31.4 % and as poor quality approximately 3 % of cases (2 % for reader MD1 and 3.9 % for reader MD2). There are no significant differences in ranking between the readers (p=0.180).

When the readers compared the low-dose images, they scored as good quality only 31.4 % of cases, as acceptable quality 47.1 % (reader MD1) and 54.9 % (reader MD2); poor quality was rated in approximately 21.6 % of cases (reader MD1) and respectively 13.7 % (reader MD2). There are no significant differences in ranking between the readers (p=0.206).

The inter-observer agreement was very good for standard-dose protocol (k = 0.83) and good for low-dose protocol (k = 0.68).

Two cases were rated as non-diagnostic by both readers; only one case was rated as non-diagnostic by one reader. The inter-observer agreement in this case was also good (k = 0.79).

**DISCUSSION**

When the readers compared the images in pairs, they both rated almost all the low-dose images (except one case) having less overall quality than its standard-dose pairs. In one case both readers graded the same quality for both images in pair. Some sample pairs images with low and standard protocol are illustrated in Figure 2.

The mean effective dose for standard protocol was 1.43 ± 0.21 mSv and for low-dose protocol was 0.85 ± 0.43 mSv. The differences between two protocols were about 38% (p < 0.05).

As we expected, the low-dose images were rated having less overall quality than the standard-dose images, but almost 98% were consider diagnostic images.
There were two cases when both radiologists marked as nondiagnostic the quality of images, but in these two cases artifacts were also noted (movement artifacts), as we instructed the readers.

Fig. 5 Brain image pairs with standard and low dose protocol.
If we analyze the agreement between the two readers we notice a very good agreement \((k = 0.83)\) that was achieved for the standard-dose protocol, but the inter-observer agreement was also good for low-dose images \((k = 0.68)\).

The radiologists also noted an increase of image noise for low-dose protocol, which is clearly visible in Figure 3b.

Our study has some limitation. We think that both readers, after few images, can easily distinguish the low-dose from standard-dose scans, so it is not a hundred percent blinded analyze. This fact was also noted by Mullins in his study (Mullins ME et al., 2004). Another limitation is that we only focus on qualitative appreciation of image quality.

**CONCLUSIONS**

CT scanners are the best tools in emergency department but represent the most important sources of medical radiation exposure. Strategies for dose-reduction should include methods that adjust the X-ray tube voltage and current, the gantry rotation time or the pitch, but it is important that the dose reduction process does not affect the quality of the diagnostic. Although the low-dose images have less overall quality than the standard-dose images, a correct diagnostic can be made. For cranio-facial trauma we suggest to use the low-dose protocols especially for young patients and for those who are undergoing multiple follow-up examinations.
REFERENCES


