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Applications of cone-beam computed tomography in fractures of the maxillofacial complex

REVIEW ARTICLE

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Abstract – Imaging plays an essential role in the evaluation of maxillofacial fractures both pre- and postoperatively. Several studies support the use of conventional two-dimensional imaging for traumas involving mainly the mandible, but for more complex situations advanced imaging modalities such as computed tomography (CT) and magnetic resonance imaging have higher indication. Nowadays, besides CT, cone-beam computed tomography (CBCT) has appeared as a reasonable and reliable alternative considering radiation dosage, image quality and comfort for the patient. The purpose of this study was to review the fracture patterns involving the maxillofacial complex, provide a technical and practical comparison between CT and CBCT, and finally present the potential applications of CBCT illustrated with clinical examples.

Imaging examination is an essential component of the management of traumatic events. It supports all aspects from diagnosis and treatment planning to assessing outcome. Unfortunately, the amount of information gained from conventional or digitally captured plain radiographs is limited by the fact that the three-dimensional anatomy of the area being imaged is compressed into a two-dimensional image. As a result of superimposition, two-dimensional radiographs reveal limited aspects of the three-dimensional anatomy requiring, in several times, combination of different conventional plain films. These problems are easily overcome using imaging techniques that can quickly produce three-dimensional images of involved structures and surrounding tissues. The benefits of three-dimensional medical computed tomography (CT) are already well established in many dental specialties. For example, several studies have supported the use of CT to the management of trauma to the maxillofacial skeleton (1, 2). It has also been used for patients requiring surgical facial reconstruction, orthognathic surgery, dental implants and complicated extractions (3). The high-radiation dose, cost, limited availability and some difficulty in interpretation have resulted in limited use of CT imaging as a definitive diagnostic tool. Recent cone-beam innovations in CT technology have invested resources to address these issues and could substantially alter the way that patients who have potentially complex traumatic fractures are managed. The aim of this study is to provide a review of the fractures that can affect the maxillofacial complex, describing potential applications of cone-beam computed tomography (CBCT) using clinical examples.

Fractures of the midface third: Le Fort I, II and III

The midfacial skeleton

The midface comprises the nasal, maxillary and zygomatic bones. Fractures in this region involve structures that are rarely fractured alone, but may result in the majority of cases in multi-fragmented or complex fractures (Fig. 1). These structures are able to support considerable force from below, but they are relatively easy to fracture as a result of ordinary forces applied from other directions. Different from the rigid protection of the mandible, midface fractures may involve several important structures, including the cranial base, which may not be properly assessed by conventional images. CBCT is able to show a larger number of fracture lines and fragments when compared with conventional images, depicting precisely the position and orientation of displaced fragments in reasonably short time interval (4). Classically, studies from Rene Le Fort have been the foundation to classify these types of fractures (5, 6). Figure 2 shows the common Le Fort fracture patterns. Rhea & Novelline (7) provided an excellent review of these fractures indicating the unique component involved in each Le Fort

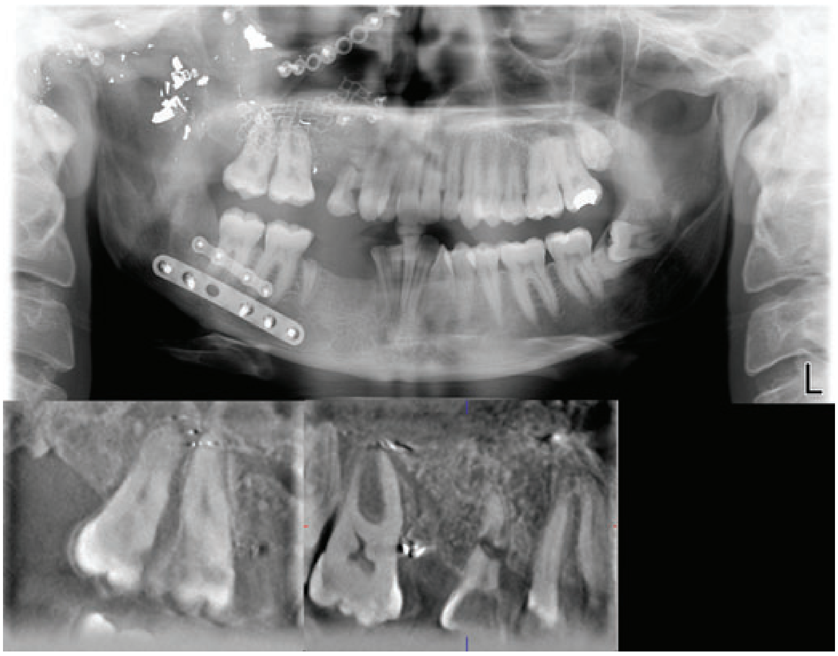

Fig. 1. Complex injury with several fragments and foreign bodies. Cone-beam computed tomography reconstructions were able to identify bony and dental fractures with more details than the panoramic radiography.

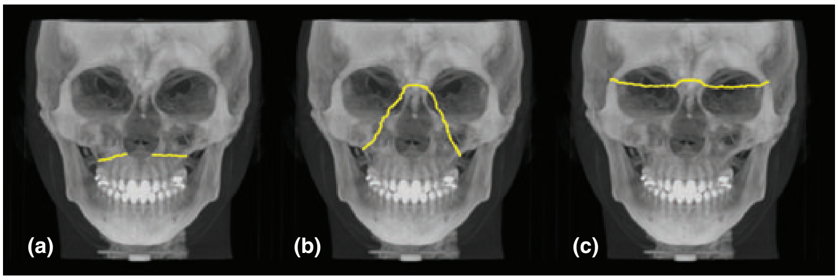

Fig. 2. Representative drawing of Le Fort fracture patterns: Le Fort 1 (a), Le Fort 2 (b) and Le Fort 3 (c).

Table 1. Anatomic structures involved in Le Fort fractures with the most effective CBCT view to identify and evaluate each fracture

Fracture	Involved structures		Best CBCT view
Le Fort I	Pterygoid process	Anterolateral margin of the nasal fossa	Coronal
Le Fort II		Inferior orbital rim	Coronal
Le Fort III		Zygomatic arch	Axial

CBCT, cone-beam computed tomography.

fracture. Table 1 presents these structures with the most effective CBCT view to identify them.

Le Fort I fractures

A low-level transversal maxillary fracture with horizontal fracture of the maxilla immediately above the upper teeth and palate. This fracture involves the anterolateral margin of the nasal fossa to the pterygoid processes across the maxilla compromising the wall of the maxillary sinus. It may occur as a single entity or in association with other fractures, but when isolated, on clinical examination, the maxillary teeth appear movable relative to the face.

Le Fort II fractures

A pyramidal or suprazygomatic fracture extending from the dorsum of nose, across the lamina papyracea below the zygomatic bone to the pterygoid processes. Therefore, this fracture differs from Le Fort I because it involves the inferior border of orbital rim keeping the anterolateral margin of the nasal fossa intact. Clinically, the patient presents movement of the teeth and nose as a unit relative to the skull.

Le Fort III fractures

High-level or suprazygomatic fractures with craniofacial disjunction. The facial bones, including the zygomas are detached from the anterior cranial base. The fracture line extends from the dorsum of the nose and cribiform plate along the medial and up to lateral wall of the orbit to the zygomaticofrontal suture. The involvement of the zygomatic arch differs this fracture from Le Fort I and II. Clinically, teeth, nose and zygomas are movable relative to the rest of the skull.

Other fractures beyond Le Fort's classification

Le Fort's work was based on low-speed impact and does not completely reflect the amplitude of trauma that is encountered nowadays. The area of the bone that fractures under traumatic impact is determined by a dynamic factor consisting of the nature of the force (i.e. energy and area of impact) and a static factor, which depends on the anatomic predisposition of the bone involved to fractures (8). A small impact area results in a localized direct fracture (i.e. trimalar midface fractures). On the other side, a force that is transmitted over a larger area of bone leads to indirect 'burst' fractures, more common at the skull base and condylar fractures with impact in the mandible (9). The following fracture patterns incorporate and complete the Le Fort classification making possible quicker and more accurate diagnosis and efficient communication.

Frontal sinus fractures

Frontal bone is considered the strongest of the facial bones. McRae et al. (10) found a high association with facial fracture and intracranial injury with cerebrospinal fluid leakage. Traumas involving the frontal plate result in destabilization of the frontal bar and evident esthetic problems. No surgical intervention is required if the fracture involves only displacement of the anterior plate, but the ideal repair period should be within 10 days of injury (8). In cases involving the posterior plate but without displacement of this structure, conservative treatment with close CT follow up is preferred to avoid possible sinus obliteration. Isolated posterior wall defects are considered rare to occur. In severe displacement or commuted fractures, open treatment with cranialization and removal of the posterior table should be applied after preoperative axial CT scan to better visualize, localize anterior and posterior table fractures, and verify possible associated pneumocephalus or brain injury. Postoperative axial scans are indicated to verify bony unity and cranialization procedure. Concerning fractures involving the frontal sinus, CBCT provides good assessment of the hard tissue component, but is not very efficient to soft tissue differentiation. In severe and extensive cases, where thorough soft tissue evaluation is important, high-resolution CT or magnetic resonance imaging (MRI) should be considered.

Nasal–orbital–ethmoid fractures

These fractures are usually associated with multiple midface structures, and visual acuity and papillary response to light should always be evaluated to assess a possible neurological injury. Nasal–orbital–ethmoid fractures (NOE) are considered to be secondary to traumatic insult to the radix area of nose, a structure with low resistance to directional forces, but beneficial to reduce injury to the intracranial structures. NOE result in comminuted-posterior displacement of the nasal bone, evident by widening of the nasal bridge, with splaying of the nasal complex, and involvement of the medial orbital wall and frontal process of maxilla. In a recent article, Sargent (11) indicates high-quality CT images to efficiently diagnose and assess bone fragments. Comparing CT and MRI, CT appears to be superior for the delineation of fine bone structures, such as the infundibular complex, orbital lamina, orbital floor and cribriform lamina, because these structures frequently present low-signal intensity in MRI, but MRI is efficient to assess orbital or intracranial complications involved in these types of trauma (12–14). Pohlenz et al. (4) advocate the use of CBCT because of its adequate image quality and uncomplicated operation resulting in better assessment and management of patients involved in midfacial fractures.

Orbital fractures

The fragile medial and inferior walls of the orbit are particularly susceptible to direct or indirect 'blowout' fractures resulting in fracture of these walls and leaving the inferior orbital rim intact. Involvement of the maxillary sinus also may be noted by the presence of air fluid level and fat herniation within this cavity. Medial wall fractures can occur as isolated events or concomitantly with other orbital fractures resulting in enophthalmos from increased orbital volume and horizontal diplopia from medial rectus restriction. This fracture should be suspected every time when periorbital trauma results in epistaxis, orbital hemorrhage, horizontal dysmotility or dystopia of the globe, and/or orbital emphysema. Because of possible structural herniation or entrapment of the infra-orbital nerve, MRI should be considered to assess the involved soft tissues (15). In fact, Ilankovan et al. (16) found MRI more sensitive, in comparison with CT, for the diagnosis of herniation and entrapment of soft tissues in orbital fractures. Recently, a study presented two cases of isolated fractures involving the orbital floor supporting CBCT as an important tool in the management of these fractures (17). For the assessment of high-contrast structures, such as the medial and lateral walls, or search for foreign bodies, CBCT appears as an applicable modality. In more severe and extensive cases, where soft tissue differentiation is essential, high-resolution CT should be preferred over MRI if there is a possibility that a metallic foreign body is present (18).

Fractures of the zygomatic maxillary complex

Considered to be common in patients following blunt facial traumas, zygomatic maxillary complex (ZMC) fractures are the second commonest facial fractures after nasal fractures and may involve zygomaticofrontal, zygomaticotemporal and zygomaticomaxillary sutures with fractures along the zygomas, orbital floor and maxilla resulting in trimalar or tripod fractures. Frontal, ethmoid, palatine, sphenoid and temporal bones may also be involved. In most cases, the maxillary sinus is filled with blood and requires intervention in the periorbital region as a result of fracture of the orbital walls. The soft tissue swelling associated with trauma may mask zygomatic fractures, showing the indication of images to rule out any involvement of these structures. CBCT is particularly indicated because it is able to provide excellent images of the involved bony structures and is effective to detect occult or suspected fractures prior to surgical reduction and fixation (Fig. 3).

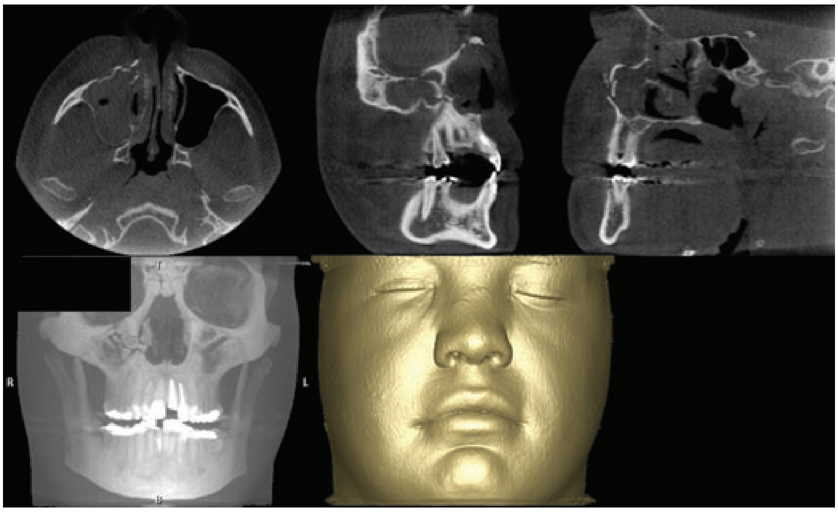

Fig. 3. Fracture of the zygomatic maxillary complex. Note the opacity in the right maxillary sinus and fractures involving the zygoma, floor of the orbital and lateral wall of the nasal cavity. Cone-beam computed tomography was able to provide information of the involved hard and soft tissues and location of the fragments.

According to Heiland et al. (19), to reduce radiation exposure of patients with fractures of the ZMC pre-, intra- and postoperative CBCT images should be used, but in patients with neurologic symptoms or additional and very extensive injuries, CT imaging is still mandatory.

Nasal fractures

Being the nose, the most prominent projection of the face, nasal fractures sustain the largest number of fractures accounting for significant percentage of maxillofacial injuries (20). This type of fracture is usually apparent on clinical examination. Radiographic examination generally gives no additional information that is helpful either in reaching a diagnosis or in deciding on the therapeutic management, but it can be performed to confirm a clinical diagnosis, to verify the displacement of the fragments and involvement of other facial bones and/or for medical–legal purposes (21).

Mandibular fractures

Mandibular fractures are classified according to their location. Higher incidence is encountered in the body and symphysis, but condyle fractures are also of relatively high incidence and will be discussed in the following topic. Clinically, malocclusions, ecchymosis in the floor of the mouth and step defects involving the inferior border are included in the possible findings. Radiographically, attention should be directed to the course of the fracture lines, involved anatomic structures and the number, size and displacement of fractured fragments. For the past decades, panoramic radiography had been considered gold standard with sensitivity superior to CT for the identification of mandibular fractures (22). Actually, Markowitz (23) found no statistically significant difference between the sensitivities of CT and plain films for the detection of these fractures. However, in a more recent study, CT presented higher values surpassing panoramic images as the gold standard for the diagnosis of mandibular fractures because of its imaging enhancing tools, better imaging quality, equivalent sensitivity in identification of fractures, decreased interpretation error and greater interphysician agreement in the identification of mandible fractures (22). Considering plain films with good diagnostic quality, both conventional and advanced imaging modalities may be used for this type of fractures, but the severity of the injury, structural superimposition, patient's functional restriction, cost and availability should also be considered.

Condylar fractures

From the mandibular fractures, the ones involving the condylar region deserve further discussion. Accidents related to falls, physical activities and involving motor vehicles are included in the possible causes of this fracture (Fig. 4). Children and young adults present

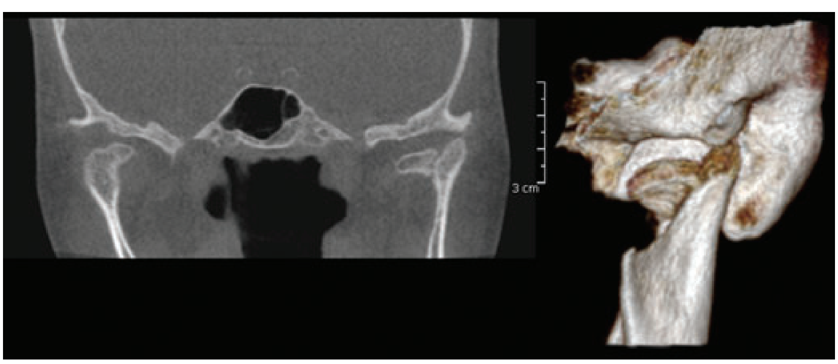

Fig. 4. Coronal and three-dimensional reconstructions of a fractured condylar head with displaced fragment.

greater adaptation with condylar remodeling and flattening of the mandibular fossa. On the other side, adults show less predictable results with functional remodeling related to patient's age. This fracture may be classified according to its location (intracapsular, extracapsular or subcondylar), type (undisplaced, displaced or dislocated) or direction of the fracture (vertical, horizontal or sagittal) (24). Another classification is given by Spiessl & Schroll (25) from type I to VI according to fracture location (low or high), with or without displacement or dislocation, and in intracapsular fractures. In 1997, the American Academy of Oral and Maxillofacial Radiology published a position paper about the imaging of the temperomandibular joint (TMJ). This study recommends conventional exams, such as lateral and frontal tomography, plain and panoramic films, when a condylar fracture is suspected; and CT for more extensive facial fractures or complex fractures of the TMJ (26). Plain films are the least expensive and require less radiation, but they have been superseded by CT and CBCT, which offer superior anatomic visualization (27). CBCT and CT appear with similar properties for the evaluation of bony components providing adequate three-dimensional hard tissue information of the whole TMJ complex. The increased radiation dose appears to be reasonable and the improvement in the diagnostic accuracy outweighs this disadvantage. MRI should be considered in cases of capsular tear and hemarthrosis, where detailed soft tissue evaluation is needed or in whom the mechanism of injury would predispose the individuals to post-traumatic internal derangement (28–30).

Comparing CBCT with medical CT

Medical CT scanner was developed in the late 1960s and subsequently patented by Hounsfield in 1973, who was awarded the Nobel Prize for medicine in 1979 because of its immediate and profound impact in diagnostic medical imaging. Early generations of the CT systems acquired information in the axial plane by scanning the patient slice by slice, by using a narrow fan-shaped X-ray beam through the patient to a single array of detectors. Over the years, technical advances have been producing scanners with more detectors. Most imaging institutions use CT with 64 rows of detectors, known as multidetector CT (MDCT), but newest machines under development use 128–256 rows of detectors allowing acquisition of simultaneous multiple slices with shorter time, lower radiation exposure and better image resolution. Some disadvantages inherited to medical CT scanners are their considerable size, cost and requirement of special room settings with lower temperature. Therefore, they are usually only found in facilities with dedicated medical imaging departments. On the other side, CBCT, also known as cone-beam volumetric tomography, applies a different concept designed for dental practice. This technology started to be developed independently in the late 1990s. The main difference between these two modalities is that in CBCT, the whole three-dimensional volume of data is acquired in a single rotation of the scanner around the patient. A cone-shaped beam captures a cylindrical volume with considerable lower acquisition time and radiation exposure. Nowadays, some CBCT scanners allow the height of the field of view (FOV) to be adjusted to capture only the necessary region to be studied complying with the 'as low as reasonably achievable (ALARA) concept', a radiation safety principle for minimizing the radiation dosage (30). About this topic, comparing the effective radiation doses derived by several CBCT systems and a 64 MDCT, Ludlow & Ivanovic (31) using the new 2007 recommendation of the International Commission on Radiological Protection found values from 70 to 560 μSv for systems with a medium FOV, from 68 to 1073 μSv for systems with large FOV, and 860 μSv for MDCT. For scanners using a small FOV, Lofthag-Hansen et al. (32) reported an effective dose ranging from 11 to 77 μSv depending on the region examined and FOV size. It is important to state that the wide range of radiation dosage values is associated with technical specifications and settings inherited by each CBCT system and not with the size of the volume acquired.

The imaging resolution is also related to the volumetric size and depends proportionally on the voxel size, a box-shaped unit of a three-dimensional volume. Today's available larger volume-CBCT scanners are capable of acquiring the entire maxillofacial region within a FOV up to 20 cm (8 inches) in diameter with isometric cubic voxel sizes from 0.2 to 0.42 mm^3 and acquisition time from 14 to 40 s. It is important to notice that the real exposure time is a fraction of the total acquisition time because of the pulsed beam used by CBCT scanners, requiring longer acquisition time, if higher resolution is desired. Smaller volume CBCT scanners capture volumes with 4 cm (1.52 inch) in diameter, enough to include just two or three individual teeth and the surrounding tissues, up to 10 cm (4 inches). These machines allow images with higher resolution using voxels with 0.08–0.2 mm^3 and acquisition time varying from 10 to 17 s. The reconstruction time for CBCT systems also varies, but usually takes less than 5 min. For medical CT, the scanning and exposure times for the skull can be significantly longer as a result of the continuous radiation exposure and larger acquired information. Medical CT scanners use linear detector arrays of cadmium tungstate or gadolinium scintillators with silicon photodiodes. Current CBCT scanners use either image intensifier tube (IIT) or flat panel display (FPD). IIT, because of the image formation and acquisition, has a bigger size and is more sensitive to distortion and vibration. FPD uses a scintillation layer acquiring the image in an amorphous silicon layer. Some advantages of FPD include a smaller size, longer working life and absence of geometric distortions inherent to the IIT machines. Sensor manufacture high cost is the great disadvantage of FPD systems.

Discussion

Single or combinations of plain films are still considered as a screening tool for the initial assessment of traumatic events involving the maxillofacial complex (33). These exams are usually limited to two-dimensional views captured using radiographic film or digital detector, and information may be obscured by distortion or superimposition of structures frequently underestimating the extension of fractures (Fig. 5). Advanced imaging modalities, such as CT and CBCT, are able to generate images easily in sagittal, coronal and axial planes eliminating the superimposition of anatomic structures (Fig. 6) (34). Using the volumetric data, three-dimensional reconstruction allows virtual visualization of the region of interest as well as the surrounding structures, such as the mandibular canal and paranasal sinuses, and contributes to management procedures, such as the manufacture and placement of fixation plates. CT and CBCT images are geometrically acceptable without structural distortion or superimposition as often seen in conventional radiographs (35). Although using dry mandibles, Loubele et al. (36) found that CBCT is able to provide comparable image quality to conventional CT. These images are useful in the diagnosis of maxillofacial fractures, but it is worth remembering that all radiographic modalities still use ionizing radiation and are not without risks. It is essential that the radiation exposure should be kept as low as possible. A single conventional plain film, compared with CT or CBCT, needs the lowest level of radiation, but when limited information is obtained by these films and further details are required for diagnosis and treatment planning or postoperative evaluation, CBCT should be considered instead of medical CT. Some studies support the contribution of CT findings for the surgical management of traumas (37, 38), but limiting factors such as cost, availability and radiation dosage promote CBCT as an acceptable alternative to evaluate maxillofacial fractures (33). Preclinical studies indicate CBCT for the evaluation of high-contrast structures with comparable quality to CT (39), but because of the low radiation applied, CBCT suffers from image noise and lack of soft tissue differentiation. On the other hand, Stuebmer et al. (40) compared the imaging findings of CT and CBCT in airgun injuries, and these authors preferred CBCT images as a result of less metallic artifacts providing superior information and diagnosis. Currently, CBCT is able to provide important information for all dental specialties not only contributing to the diagnostic accuracy of the maxillofacial complex but also decreasing cost and radiation exposure to the patient considerably (41, 42). Several studies show application of CBCT in orthodontics, endodontics and periodontics for the evaluation of implant sites and pathologies involving the maxillofacial region and assessment of the TMJ complex and upper airway in patients with sleep apnea (43–46). Imaging thus is an essential part of the diagnosis and management of fractures involving the maxillofacial complex. Patients involved in traumatic events should be imaged according to the degree of injury respecting the ALARA principle. Conventional films deliver less radiation, but may miss important information. CBCT is able to provide excellent information of bony structures but is not able to effectively assess the soft tissue components. CT provides good resolution of soft and hard tissues, but delivers the highest amount of radiation. Advanced imaging modalities, such as CT and MRI, are progressively replacing conventional two-dimensional films for maxillofacial traumas and are increasingly being performed to detail and classify these traumas. MRI is an alternative to CT in evaluating events involving paranasal sinuses and soft tissues, but its decreased ability to delineate bony detail and its higher cost should be considered (47). CT is more indicated in very extensive and emergency cases because of higher soft tissue image resolution. If this modality is unavailable, two-dimensional images may be an alternative, but important information, even with the best conventional technique, is frequently lost. Therefore, CBCT appears as an acceptable alternative to CT providing important information with less radiation.

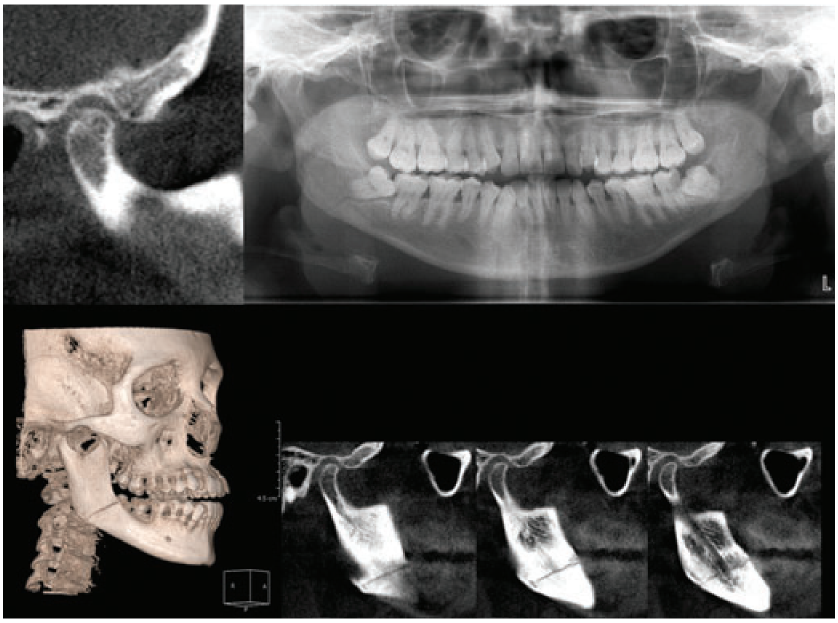

Fig. 5. Fractured right condylar head and body of the mandible without significant displacement of the fragments. Note that the panoramic did not show the condylar involvement depicted clearly in the cone-beam computed tomography.

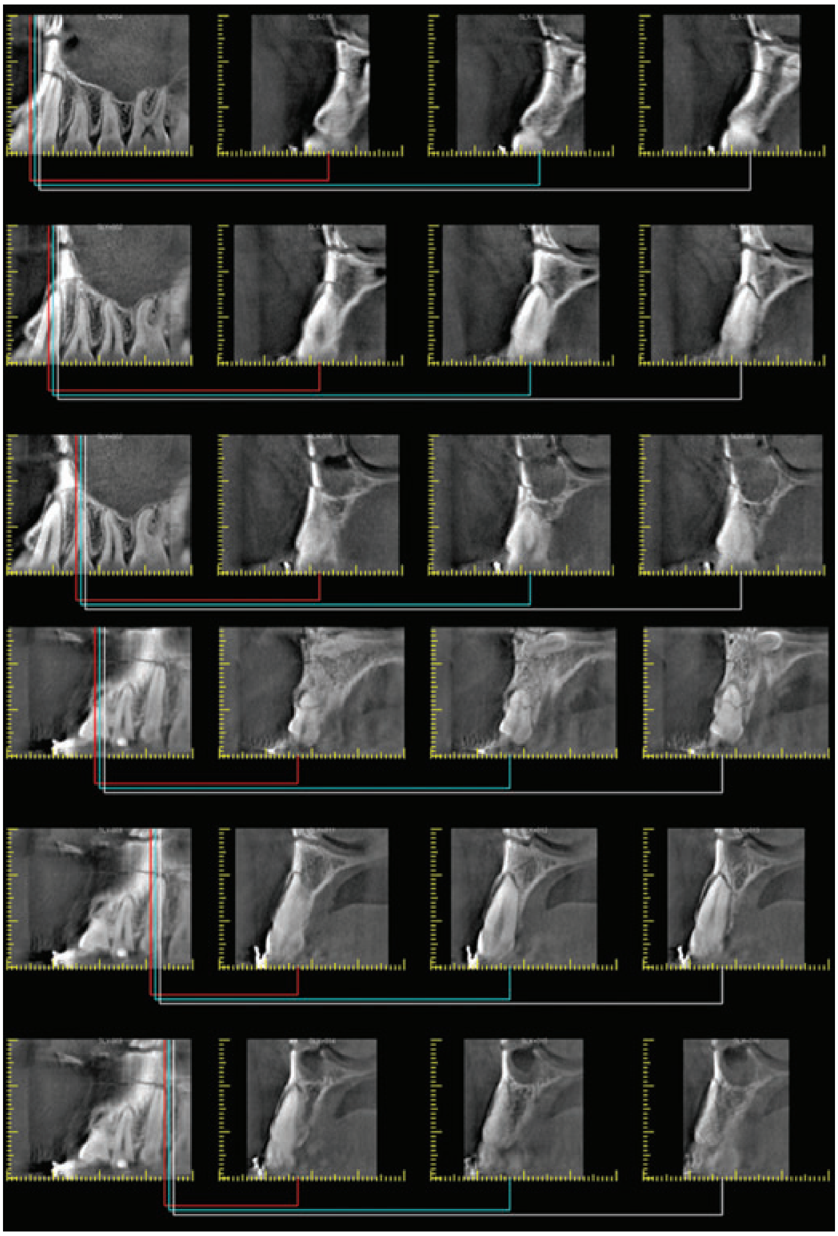

Fig. 6. Midface fracture (Le Fort 1) with alveolar and dental involvement. This small volume cone-beam computed tomography presents high resolution providing images with high details.

Table 2. Advantages and disadvantages of imaging modalities used to evaluate fractures in the maxillofacial complex

Modality	Advantages	Disadvantages
Plain films	Availability Lowest radiation exposure Lower cost	Two-dimensional images Need for more than one projection
CT	Three-dimensional images Hard and soft tissues differentiation	Availability Highest radiation exposure Higher cost
CBCT	Three-dimensional images Hard tissue differentiation Lower radiation exposure than CT Less metallic artifacts than CT	Lack of soft tissue differentiation
MRI	No radiation Soft tissue differentiation	Availability Higher cost

CT, computed tomography; CBCT, cone-beam computed tomography; MRI, magnetic resonance imaging.

From a radiation protection point of view, conventional films still deliver the lowest doses to patients, but when more details are required, CBCT should be considered. These systems represent considerable reduction in radiation exposure and lower cost with an image quality adequate for most of situations and provide an effective and safe alternative to assess and manage patients involved in maxillofacial traumas. Table 2 summarizes the main features highlighting advantages and disadvantages of each imaging modality applicable to evaluate fractures in the maxillofacial complex. Hence, nowadays several modalities are available for the diagnosis and management of patients involved in traumas to the maxillofacial regions. Updated knowledge about the correct indication of the available conventional and advanced imaging modalities should always be kept in mind to provide the best health-to-risk ratio for the patient.

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