Radiological investigation of acute mandibular injury

ABSTRACT

This article focuses on the different imaging modalities used to evaluate acute mandibular fractures and explores important concepts relating to their diagnosis, investigation, and treatment. Significant focus will be given to exploring general management principles, considerations regarding first-line imaging, and recent technological advancement. Computed tomography (CT) is the preferred method when attempting to identify acute mandibular fractures, particularly in trauma patients, and has very high specificity and sensitivity. Multidetector CT now represents the standard of care, enabling fast scan times, reduced artifact, accurate reconstructed views, and three-dimensional (3D) reconstructions. Cone-beam CT is a newer advanced imaging modality that is increasingly being used worldwide, particularly in the ambulatory and intraoperative setting. It produces high-resolution images with submillimeter isotropic voxels, 3D and multiplanar reconstruction, and low radiation dose, however is less widely available and more expensive. Ultrasound is a valuable method in identifying a fracture in unstable patients, but is limited in its ability to detect nondisplaced fractures. Magnetic resonance imaging is useful in determining the presence of soft-tissue injury. CT angiography is invaluable in the assessment of potential vascular injury in condylar fracture dislocations.

Keywords: Fracture, imaging, jaw, mandibular, trauma

INTRODUCTION

Mandibular fractures represent a common type of facial fracture in maxillofacial trauma, occurring most frequently in young men between the ages of 25 and 34 years.[1,2] Because of its prominence and mobility, the mandible accounts for up to 75% of all facial fractures.[1,3] Accordingly, they should be considered in all cases of facial trauma and should be assumed if a patient presents with trismus, fractured teeth, step deformity, or malocclusion.[4] It is the most commonly reduced of all the viscerocranial structures in mandibular dislocations and accounts for up to a quarter of all casualty department presentations for maxillofacial fractures.[4,5] An epidemiological survey by Haug *et al*. reported that motor vehicle accidents and assaults alone were responsible for ten times as many cases as all other factors combined.[1] The most common cause of mandibular fractures is motor vehicle accidents, which are mostly due to the ever-growing numbers of vehicles and increasing speed limits.[6] The second most common cause is assault, where fractures of the gonial angle are frequently seen.[5,6] Mandibular fractures are also shown to happen more often in regions of reduced socioeconomic status secondary to increased alcohol abuse, violence, and assault.[7] They occur most often in the parasymphysis, horizontal ramus, condyle, and gonial angle, with far fewer seen in the ramus (2%–4%) and coronoid process (1%–2%).[8,9] Gonial angle injuries are also more likely to be associated with a physical attack.[9]

Imaging studies enable the extent of the fracture to be identified. The optimal end result is normal or near-normal occlusion, while avoiding complications. We will discuss about the various categories of fractures in addition to the diverse range of radiological studies utilized to evaluate this

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injury. Significant focus will be given to exploring general management principles, considerations regarding first-line imaging, and recent technological advancements.

METHODS

A search was performed of four databases, including PubMed, Medline, Embase, and Scopus, for pertinent articles from January 1990 until December 2018. The reference lists of all relevant studies identified were parsed for further relevant articles. There were no restrictions relating to language. The following terms and their combinations were used as either keywords or MeSH headings: "mandible," "fracture," "traumatic," "imaging," "computed tomography," "CT," "X-ray," "radiography," "MRI," "magnetic resonance imaging," "US," and "ultrasound."

Categorization and general management principles

The classification of the mandibular fracture is important because it subsequently influences the management approach. General principles include reducing fractures of tooth-bearing segments and those with the least displacement first.[10] There are different treatment strategies depending on the site, displacement, comminution, number of fractures, and whether or not it is unilateral/bilateral. It is particularly important to look for basal wedge fragments at the lower border of the mandible as they are not readily seen intraoperatively, and missing this finding can lead to an inappropriate fixation strategy.[11,12] Other considerations include the potential risk to important neurovascular structures such as the inferior alveolar nerve and facial nerve, dental status, risk of scarring, baseline level of function and health, and oral hygiene.[13] It is crucial to bear in mind that because of its horseshoe shape, a fracture or dislocation is more likely than not to be accompanied by another fracture or dislocation, often on the opposite side.[14] Thus, over 50% of mandibular fractures can be classified as complex and bilateral.[15] However, because the temporomandibular joint (TMJ) participates in the dissipation of force, it does not exhibit classic fracture patterns' characteristics to other ring-like structures.[15,16]

Dingman and Natvig in their classification organized the mandible into seven separate areas (symphysis, body, alveolar process, gonial angle, ramus, condyle process, and coronoid process).[17] The Kazanjian and Converse classification relates to three different types. In a Type I fracture, there are teeth on both bony fragments. If there are teeth on only one bony fragment, then this is a Type II injury. If there are no teeth on either fragment of bone, this is then a Type III injury.[18] A mandibular fracture in the gonial angle and horizontal ramus can also be categorized by how the surrounding musculature acts. Favorable fractures occur when the musculature acts to oppose the fragments together, whereas unfavorable fractures have the opposite effect.[19] Similarly, they can also be staged in accordance with the F_0–F_4 system, with F_0 being an incomplete fracture, F_1 a single fracture, F_2 a multiple fracture, F_3 a comminuted fracture, and F_4 a fracture with a bone defect/loss.[20] The higher the score, the higher the chance of inferior alveolar nerve involvement and postoperative sequelae. Condylar fractures can be additionally categorized by the Lindahl classification. In this classification, condylar fractures are divided into condylar head, neck, and caudal fractures, depending on the fracture position.[21] It is important to note that fractures of the condylar head are also intracapsular because the joint capsule extends to the condyle neck, whereas the caudal or subcondylar fracture extends inferiorly from the sigmoid notch. Based on the fracture fragment, condylar fractures are then further categorized into undisplaced, deviated, displaced, or dislocated. The most frequently seen is that of anteromedial condylar head displacement, which occurs in fractures below the lateral pterygoid muscle.[22]

Generally, open reduction and internal fixation (ORIF) will be required for fractures of the gonial angle, body, symphysis, or parasymphysis, given they frequently involve tooth-bearing segments and periodontal ligaments, hence making them open fractures.[23,24] Although this distinction is generally made clinically, soft-tissue gas is a useful indicator in imaging.[24] The exception is if the fracture line extends into the territory of a third mandibular molar without concomitant gingival break.[24] There is currently no consensus with regard to the management of teeth in the line of mandibular fractures, with more permissive approaches being favored recently with the recognition that the presence of teeth helps with maintaining occlusion.[25-27] However, it is important to look for factors on imaging that favor extraction including associated crown fractures, severe tooth decay, poor periodontal condition, and dislocation.[28]

Another important group are edentulous or atrophic mandibular fractures. A classification by Luhr *et al*. divides mandibular atrophy into three classes I–III, with III being the most severe and representing a mandibular body height of <10 mm.[29] Classes I and II represent mandibular body heights of 16–20 and 11–15 mm, respectively. These have a higher rate of malunion and nonunion secondary to the reduced area of contact between the injured bone fragments, reduced opposition to antagonist muscles, and poor osteogenic potential. Generally, ORIF will be required to achieve an acceptable outcome in this subgroup of patients.[30]

In addition, caudal fractures with unfavorable characteristics including significant shortening and angulation of the ramus have an increased risk of malocclusion and would benefit from ORIF.[31] However, the approach to caudal fractures is generally with maxillomandibular fixation given the high incidence of complications with ORIF, most prominently including facial nerve injury and parotid fistula.[31]

The role of closed reduction and external fixation is diminishing, however there are specific scenarios where it is appropriate, particularly in the emergent trauma setting. For very unwell patients with multiple severe injuries, this technique is appropriate given external fixation can be performed very quickly and can reduce the risk of secondary brain injury from intraoperative hypotension or hypoxia.[32,33] For grossly comminuted or "defect" fractures, particularly with significant associated soft-tissue loss and infection, external fixation will be required as part of a multistage surgical approach.[33] They are also commonly used in undisplaced closed favorable fractures, however increasingly, condylar fractures are being repaired with an ORIF approach, particularly bilateral condylar fracture and high condylar fractures with associated condylar head displacement and loss of vertical height of the mandibular ramus.[34,35] Fractures involving the coronoid process are rare, and generally management with observation and physiotherapy is indicated, with removal of the coronoid process indicated for ongoing trismus.[36]

DISCUSSION AND REVIEW OF LITERATURE

The potential for mandibular fracture should be recognized quickly because of the risk of complications with subsequent dysfunction. These include non- and mal-union, TMJ dysfunction, traumatic arthritis, and ankylosis.[4,19] In addition, rapid identification of flail mandible, particularly trifocal, bilateral gonial angle, and bilateral body fractures, should be made due to the threat of airway compromise from associated complications.[37] Failure to recognize this has the potential to lead to significant morbidity and mortality. Most patients with suspected mandibular fractures in the trauma setting have computed tomography (CT) imaging to look for other injuries, for example intracranial hemorrhage, organ rupture, or cervical spine fracture. For multiple trauma cases, scanning of the facial bones and orbit can be readily added to whole-body CT-based trauma imaging protocols.[38,39] Attempting to elicit the severity of a fracture clinically in this setting is impractical given the presence of distracting injuries and potentially altered level of consciousness. Concurrent injuries are fairly typical in mandibular fracture patients, specifically in the intracranial region.[38] They can be present

in up to 20% of mandibular fractures, hence the need for additional imaging of the head if there is a suspicion of head injury.[40] Cervical spine injuries can also occur concurrently and must be ruled out in people with reduced Glasgow Coma Scale or have come from a high-speed motor vehicle accident with distracting injuries.[41] It is interesting to note that the presence of multiple mandibular fractures has a negative association with cervical vertebrae injury, perhaps secondary to a force dissipation mechanism.[42] On the whole due to the high risk of concurrent injuries, CT of these regions is generally carried out together.[43]

Treatment decisions and pathways are now progressively reliant on multidetector CT, particularly in preoperative assessment.[10,44] This is because if the extent and type of the fracture pattern, together with associated injuries, is not identified, then potentially inappropriate fixation or selection of a nonoptimal surgical plan and strategy may result.[10,38,44] A study by Wilson et al. compared a cohort of 42 consecutive patients with mandibular fractures who received both CT and panoramic tomography imaging.[45] The sensitivity of CT for the detection of mandibular fractures compared to panoramic tomography was higher (100% vs. 86%), with the surgical management being changed in six patients. Similarly, Roth et al. showed greater sensitivity for CT (100% vs. 86%), with superior interobserver agreement.[46] Multidetector CT has been shown to have better sensitivity, particularly for fractures of the gonial angle, ramus, or condyle.[45,46] Increasingly, surgical evidence and protocols support the use of ORIF to facilitate faster recovery and re-establishment of structure and function.[10,38] Hence, in patients with a high pretest probability, multidetector CT is increasingly playing the dual role of the initial modality of choice for making the diagnosis together with facilitating planning of the surgical approach.

By and large, multidetector CT now represents the first-line imaging modality of choice if it can be achieved in patients with suspected fractures of maxillofacial trauma and is generally considered to represent the standard of care.[47] Health-care cost containment and lack of availability represent the main factors that limit adoption, however the changed medicolegal environment is gradually tilting the scale to increasing utilization.[48] Multidetector CT is relatively weaker for the characterization of concomitant dental trauma, which is important, for example, when considering symphyseal and body fractures (which generally always cross the tooth row) and gonial angle fractures (which generally involve the mandibular third molar).[19] When there is concern regarding the status of the mandibular third molar or other dental structures, further panoramic tomography imaging can be

sought.[24] However, this is proving increasingly unnecessary, with further improvements in technology allowing for increasingly high-resolution multiplanar reformatting and three-dimensional (3D) reconstruction with acceptable levels of artifact.[19]

Multiplanar formatting allows coronal and sagittal views to be reconstructed from the axial plane, hence permitting for projections where there is minimal superimposition. Accordingly, condylar and symphyseal fractures are seen well in contrast to plain radiography.[49] Furthermore, this overcomes the issues relating to an immobilized trauma patient. CT also allows for a 3D reconstruction of the mandible which affords a number of advantages for the surgeon, particularly with regard to preoperative planning. It is useful in determining the categorization and severity of the fracture and favorable/nonfavorable status and allows for better analysis of displacement, including location, direction, and magnitude.[50] However, this can represent a potential pitfall as 3D volumetric reconstruction is associated with a partial volume averaging artifact, therefore smaller structures are best reviewed with high-resolution reconstructed axial, sagittal, and coronal slices.[51] The overall sensitivity for CT in detecting mandibular fracture is higher than that for plain radiography. Furthermore, the decreased sensitivity of plain radiography is also contributed to by the fact that nondisplaced fractures may not be apparent for up to 10 days with this modality, and hence is frequently not seen initially.[52] There is a greater level of sensitivity in analyzing a fracture with CT, however this comes at the cost of increased radiation dose (around 2 mSv, in comparison to a plain radiograph at 0.010 mSv).[53] However, low-dose CT applications with dose-reduction programs are increasingly being performed, with doses of <1 mSv in maxillofacial CT being achieved in new multidetector CT scanners.[54] Previously, weaknesses of CT included lengthier scan times with the potential for the production of artifact, particularly metallic artifact and motion blur in multiplanar and 3D volumetric reconstructed views.[55] However, modern multidetector CT scanners, particularly higher slice systems, have very fast scan times with significant improvement in z-axis spatial resolution, allowing for coronal and sagittal views to be reconstructed quickly.[56] In addition, the development of iterative metal artifact reduction algorithms and dual-energy multidetector CT techniques has helped to overcome artifact from beam hardening.[57,58]

Cone-beam CT is a newer advanced imaging modality that is increasingly being used worldwide, particularly in the ambulatory and intraoperative setting.[59,60] It involves the use of a cone-shaped beam and a flat panel detector which captures all the images in a single rotation without patient movement, with most scanners requiring a seated posture.[59,61] Cone-beam CT can generate isotropic voxels to as small as 0.075 mm^3 and can afford multiplanar reconstruction and 3D volumetric reconstruction.[61] It has significantly reduced radiation dose up to twenty-five times lower when compared to multidetector CT and is less susceptible to beam-hardening artifact.[47,61] Multidetector CT, however, has superior soft-tissue contrast and is better able to characterize the fracture fragments and their relationship to surrounding musculature, the extent of hemorrhage, and the presence of foreign bodies.[61] In the acute emergency setting, dedicated cone-beam CT imaging is generally impractical or unavailable when compared to multidetector CT imaging.[47,62] In the ambulatory setting, it affords high-quality information both for diagnosis and surgical planning compared to plain radiography but is less available and more expensive.[47] This is demonstrated in a study by Kaeppler *et al*. where follow-up cone-beam CT was performed in 164 patients with equivocal radiographic findings, resulting in an altered management plan for 9.52% of patients.[63]

The main utility of plain radiography as a first-line imaging modality is triaging for simple fractures in the ambulatory setting where CT imaging is unavailable.[47,64] The advantages are the cheaper cost, more widespread accessibility, and decreased radiation dose.[64,65] Panoramic radiography can be combined with the standard series of X-ray views or used as a strategy in isolation, with studies showing similar or superior sensitivity for the identification of simple fractures when assessed against standard radiographs.[66] They display the whole mandible in a single plane and are the most helpful radiograph in identifying a mandibular fracture, with a higher sensitivity (92% vs. 66%).[67] They show fractures in the horizontal ramus well and also permit superior assessment of any type of comminution or displacement. Weaknesses include poor visualization of condyloid process fractures and artifacts secondary to poor technique.[68] In addition, minimally displaced anterior fractures can be misinterpreted where there is superimposition of the cervical spine. For patients needing to stay supine with a collar on, only anteroposterior/lateral/oblique views are attainable,[69] with the main limitation here being that the condylar region is poorly visualized and displacement is difficult to assess.[69,70] An orthopantomogram, Clementscitsch, and posteroanterior views are unfeasible in this case given the person is unable to stand or move his/her neck; hence, in these patients, CT is the preferred modality by default.

Ultrasound has been shown to be helpful in finding displaced fractures, with very high sensitivities seen.[71,72]

It is particularly useful for the recognition of fractures with bony step-off, but it is limited in its ability with respect to nondisplaced fractures.[71,73] However, resolution can be improved to 0.01-cm displacement with high-resolution ultrasonography, with the trade-off being a reduced field of view.[74] A systematic review by Adeyemo and Akadiri on ultrasonography in maxillofacial fractures showed that ultrasound performed less well in the detection of intracapsular condylar fractures due to the superimposition of the zygomatic arch.[75] The main benefits of ultrasonography are that it is a rapid imaging strategy, is reasonably economical, and has no ionizing radiation. This would be specifically valuable in trauma where the patient is too unstable or in cases where the patient declines CT scanning due to radiation, for example pregnancy. Unfortunately, ultrasonography supplies limited information relating to the extent and classification of the fracture because of technical limitations such as the number of views and spatial resolution attainable. It also has the additional significant weakness of being operator dependent.[71,73]

Magnetic resonance imaging (MRI) is generally not used in the acute stages for patients with maxillofacial trauma as CT is faster and superior in assessing for suspected bony injury and also has the advantage of being a round-the-clock service. However, in stabilized patients with suspected soft-tissue injury, MRI does play a significant role and has the advantage of not using ionizing radiation. Acute traumatic TMJ disc displacement and perforation/rupture of the retrodiscal tissue is significantly associated with TMJ ankylosis and other sequelae, with MRI representing the sole imaging modality that can dependably and adequately assess the anatomical structures for this.[76] Significant morbidity can result, however, unfortunately, a number of factors including cost and availability prevent the widespread imaging of condylar fractures for soft-tissue injury.[47] At this stage, more focus is placed on detecting the patterns of injury on CT that might be prognostic of further soft-tissue complications and that may profit from ORIF.[77] High condylar fractures with associated condylar head displacement and loss of vertical height of the mandibular ramus have been shown to have an association with higher rates of disc displacement and perforation/rupture of the retrodiscal tissue.[35] These are factors that eventually lead to the development of TMJ ankylosis, poor functional and anatomical outcomes, and the potential need for future joint replacement.[76]

CT angiography is important to perform for condylar fractures with associated dislocation. This is done to look specifically for vascular complications, most prominently including dissection, particularly of the internal carotid artery, active hemorrhage, pseudoaneurysms, arteriovenous fistula, and aneurysms.[78] A high index of suspicion and early detection is paramount, as early surgical intervention or endovascular therapy can limit subsequent morbidity.[78,79] Pseudoaneurysms and dissections, particularly those involving major vessels, represent fairly uncommon but potential serious complications, however an increasing number of cases are being reported in literature.[79-85] This may be reflective of the increased access to imaging modalities and technological advancements.[79,80] Other important nonvascular complications associated with condylar fracture dislocations include fractures of the tympanic plate and mandibular fossa, associated dislocation into the external auditory canal and middle cranial fossa, abnormal bony development, and cranial nerve injury.[86]

CONCLUSION

This article has examined the different imaging modalities used to evaluate acute mandibular fractures and explored important principles underpinning diagnosis and management and recent technological advances. Plain radiographs have traditionally been used to identify mandibular fractures in stable ambulatory patients. CT is the preferred method when attempting to identify acute mandibular fractures, with very high specificity and sensitivity. Multidetector CT now represents the *de facto* technological standard of care, enabling fast scan times, reduced artifact, and accurate multiplanar and 3D reconstructions. Cone-beam CT is a newer advanced imaging modality that is being used predominantly in the ambulatory and intraoperative setting, allowing for high-resolution images with submillimeter isotropic voxels, 3D and multiplanar reconstructions, and lower radiation doses. Ultrasound is a useful modality for identifying fractures in grossly unstable patients but is limited in its ability to detect nondisplaced fractures. MRI is valuable in the assessment of soft-tissue injury. CT angiography is invaluable in the assessment of potential vascular injury in condylar fracture dislocations.

Conflicts of interest
There are no conflicts of interest.

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