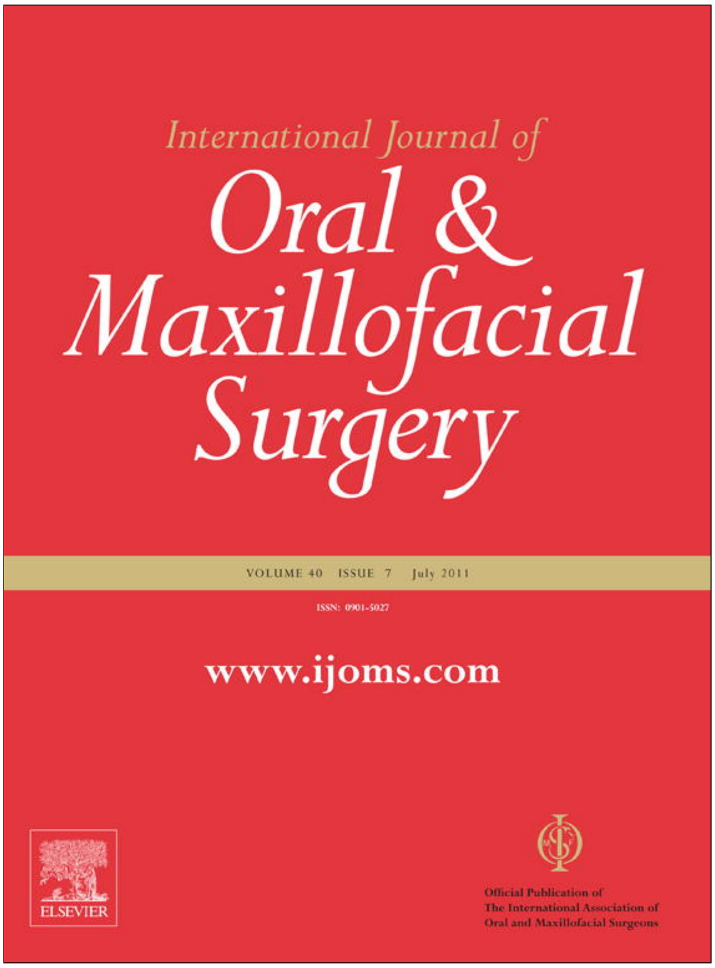
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Invited Review Paper
Trauma

A systematic review of the diagnostic role of ultrasonography in maxillofacial fractures

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Abstract. This systematic review assessed the diagnostic value of ultrasonography in maxillofacial fractures. A computerized literature search of MEDLINE, PubMed and GoogleMed databases was conducted for publications on diagnostic ultrasound and maxillofacial fractures in English. Search phrases were 'maxillofacial fractures' or 'midfacial fractures' or 'zygomatic complex fractures' or 'nasal bone fractures' or 'orbital fractures' or 'mandibular fractures' combined with 'ultrasound' or 'ultrasonography'. The Boolean operator 'AND' was used to narrow the searches. 17 articles published between 1992 and 2009 were reviewed: two on midfacial fractures, nine on orbital fractures, three on nasal fractures, and two on mandibular fractures. One article described case series of ultrasonographic diagnosis of mandibular and midfacial fractures. The sensitivity and specificity of ultrasound in detecting orbital fractures were 56–100% and 85–100%, respectively, whilst that of nasal fractures were 90–100% and 98–100%, respectively. Sensitivity and specificity of ultrasonography in detecting zygomatic fractures were >90%. For mandibular fractures, the sensitivity and specificity was 66–100% and 52–100%, respectively. Much evidence justifies the use of diagnostic ultrasonography in maxillofacial fractures, especially fractures involving the nasal bone, orbital walls, anterior maxillary wall and zygomatic complex. The sensitivity and specificity of ultrasonography is generally comparable with CT.

Keywords: systematic review; ultrasonography; maxillofacial fractures.

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Conventional plain radiography and computed tomography (CT) scans are the traditional diagnostic tools for maxillofacial injuries[1,2,9,13,23,28]; CT being the gold standard[13,28]. Both are associated with disadvantages and limitations. In conventional radiography, the superimposition of images of the overlying structures sometimes makes definite radiological interpretation difficult[13,16]. Another disadvantage is that real-time image visualization is impracticable without digital technology, hence, only a hard copy image of two-dimensional plain films is available for evaluation. These limitations have largely been overcome by CT, but the disadvantages of CT imaging include limited access to facilities, high cost, and high radiation exposure[5]. In addition, in patients with metallic implants there can be blurring of the image due to artefacts generated by the metal[19]. Also, CT requires special patient positioning, which may not be possible in uncooperative

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patients and in those who may have suffered cervical spine injuries[6,19].

Rapid developments in computing hardware and microelectronic technology have facilitated technological advancement in ultrasonography in the last three decades, making it applicable not only to soft tissues but also to bony lesions of the head and neck[21,23]. This has increased interest in evaluating ultrasound imaging as an alternative to conventional radiography and CT in the diagnostic evaluation of maxillofacial fractures[2,6,14–20,22]. Most literature reports are very promising, but whether ultrasonography can replace conventional radiography and CT in the diagnosis of maxillofacial fractures has still to be established.

If evidence in support of the utility of ultrasonography in maxillofacial trauma imaging is established, a new level of evidence-based practice, leading to cost-effectiveness and optimal risk control in maxillofacial trauma care may have been revealed. Evidence-based practice involves integrating individual clinical expertise with the best available external clinical evidence from systematic research[29]. The systematic review of evidence on new diagnostic, prognostic, therapeutic, rehabilitative or preventive regimens is desirable. In this systematic review, a pioneering effort, based on best available research, is made to evaluate and appraise the current role of diagnostic ultrasonography in maxillofacial fractures. The objectives are to ascertain the level of evidence available, to highlight the specific indications and to identify any current limitations to the use of ultrasonography as an alternative to radiation imaging techniques in the diagnostic evaluation of maxillofacial fractures.

Materials and methods

In a multi-staged approach, a rigorous search for articles on ultrasonography in maxillofacial fractures was conducted. The first step involved a search for existing systematic reviews and/or meta-analyses on the subject via the following gateways: Cochrane reviews; ADA. EBD systematic reviews (American Dental Association. Evidence-based Dentistry); HINARI library (Health InterNetwork Access to Research Intiatives); PubMed and Essential Evidence plus (www.essentialevidenceplus.com). In the second stage, a computerized literature search of MEDLINE, PubMed and GoogleMed databases was conducted for publications on ultrasound and maxillofacial fractures. Mesh phrases used for the search were 'maxillofacial fractures' or 'midfacial fractures' or 'zygomatic complex fractures' or nasal bone fractures' or 'orbital fractures' or 'mandibular fractures' combined with 'ultrasound' or 'ultrasonography'.

The Boolean operator 'AND' was used to combine and narrow the searches. The search was limited to articles originally published in English or for which a full text English translation was available. During this round of searching, abstracts were reviewed and the relevant full text articles were selected. The third step involved a manual search of the reference lists of all the selected articles to identify other relevant articles for final selection. Articles were selected if the following inclusion criteria were fulfilled: availability of full text article in English; studies were performed on humans; CT or conventional radiography or intraoperative findings were the reference methods used to compare ultrasonography; site of fracture evaluated was unambiguously stated; type and resolution (frequency) of the transducer used was clearly specified; outcomes were measured in terms of sensitivity and specificity or comparison of absolute number of fractures detected by the specific imaging techniques. Full texts of all selected articles were critically appraised for methodology (including adequate description of ultrasound evaluation technique, and the reference method to which the diagnostic value of ultrasound was compared), validity of results, and inferences made.

Results

The initial search for previously published systematic review on the use of ultrasonography in maxillofacial fractures yielded nothing. Subsequent searches for studies relevant to the subject produced 17 articles that satisfied the inclusion criteria. These articles were published between 1992 and 2009. They consist of two articles that considered midfacial fractures as a group (S8 and S15), nine articles dedicated to the study of orbital fractures (S1, S2, S5, S6, S9–13), three articles specific to nasal fractures (S14, S16, and S17), and two articles on mandibular fractures (S4 and S7). One of the articles described case series of ultrasonographic diagnosis of mandibular and midfacial fractures (S3) (Table 1). All the articles were descriptive and comparative in nature. With the exception of the single case series, all were either prospective or cross-sectional in design. Investigator blinding was performed in five studies whilst a control group was introduced in four studies. The sample size ranged from 10 to 171 subjects in the experimental studies whilst five cases were involved in the case series. CT was the commonest imaging modality to which ultrasonography was compared. Some investigators used either conventional plain radiographs, or intraoperative observations or combinations of these reference methods (Table 1). Transducers with frequency ranging between 7.5 MHz and 30 MHz were employed in the studies. Curved probes and small probe designs were used in most cases, whilst a few investigators employed linear probes. The closed eye technique was preferred for all orbital ultrasonographic imaging.

Studies that investigated the application of ultrasonography in midfacial fractures as a group reported good correlation with reference methods in the detection of fractures of the anterior wall of maxillary sinus, nasal bridge, displaced fractures of the zygomatic arch, medial and lateral orbital walls (Table 1). Isolated orbital floor fracture, especially in the posterior aspect, was not adequately visualized by ultrasound scans.

The sensitivity and specificity of ultrasound in detecting orbital fractures range from 56% to 100% and 85% to 100%, respectively whilst that of nasal fractures range from 90% to 100% and 98% to 100%, respectively (Table 1). Sensitivity or specificity of ultrasonography in detecting zygomatic fractures was greater than 90% in published studies (Table 1). Only two studies investigated mandibular subcondylar/ramus fractures and these studies reported sensitivity and specificity in the range of 66–100% and 52–100%, respectively. Detailed characteristics and other findings of all selected studies are presented in Table 1. The limitations of diagnostic ultrasonography and factors affecting validity of ultrasound imaging in maxillofacial fractures based on the published literature are highlighted in Tables 2 and 3, respectively.

Discussion

Ultrasound is a form of energy that consists of high frequency mechanical vibrations not audible to the human ear[9,23]. Ultrasonography was first used in medical practice during World War II when it was introduced to obstetric practice by Ian Donald[23]. It is a non-invasive diagnostic procedure and does not produce ionization. It is rapid and painless and has no known deleterious biological effect[2]. When it was introduced to head and neck medicine, it was restricted to the imaging

Table 1. Comparison of characteristics and findings between selected studies.

Study no.	Article	Design	Controlled or not	Sample size	Type of fracture	Reference methods	Transducer type	Outcome
S1	Forrest et al.[6] (1993)	Prospective	Controlled	18	Orbital walls	CT	10 MHz curvilinear	Se—92%,
		Single blind					Closed eye technique	Sp—100% Ac—100%
S2	Lata et al.[22] (1993)	Prospective	Controlled	19	Orbital walls	CT	10 MHz, small probe	Se—92%
							Closed eye technique	Sp—100% PPV—100%
S3	Hirai et al.[11] (1996)	Case series	Not controlled	5	Nasal bone (1)	Intraoperative findings, plain radiograph	15 MHz, 30 MHz small probe	Good correlation in all cases
					Orbital rim (1) Anterior wall maxilla (1) Angle of mandible (1) Mandibular symphysis (1)			
S4	Kleinheinz et al.[20] (1997)	Cross-sectional	Not controlled	30	Subcondylar fractures	Plain radiograph (orthopantomographs)	7.5 MHz, linear	Se—100%
								Sp—100%
S5	Jenkins and Thau[19] (1997)	Prospective	Not controlled	20	Orbital floor	CT and intraoperative findings	7.5 MHz, curvilinear	Se—85%
							Close eye technique	Sp—88% Ac—86% PPV—92% NPV—78%
S6	McCann et al.[25] (2000)	Prospective, single blind	Not controlled	22	Zygomatico-orbital complex	Plain radiograph and intraoperative findings	7.5 MHz, convex	For orbital floor; Se—100%, Sp—95%, zygomatico-maxillary; Se—94%, Sp—100%.
S7	Friedrich et al.[8] (2001)	Prospective	Not controlled and ramus	32	Mandibular condyle	Plain radiograph (orthopantomograph and PA view)	7.5 MHz, small probe	Se—66%
								Sp—52%
S8	Friedrich et al.[7] (2003)	Prospective	Controlled	81	Midfacial fractures	CT	Small part applicator	Good correlation for depressed zygomatic arch, multiple fractures of zygomatic complex ± anterior orbital floor nasal bridge, anterior wall of maxillary sinus Poor correlation for non dislocated fractures, complex fractures, and lateral extension of fracture lines
S9	Jank et al.[17] (2004)	Prospective, single blind	Not controlled	58	Orbital floor	Intraoperative finding and comparison with CT	7.5 MHz, curvilinear	Se—94%
							Closed eye technique	Sp—57%

Table 1 (*Continued*)

Study no.	Article	Design	Controlled or not	Sample size	Type of fracture	Reference methods	Transducer type	Outcome
S10	Jank et al.[16] (2004)	Prospective	Not controlled	40	Medial and lateral	CT	7.5 MHz, curved	Ac—96%
					Orbital walls		Closed eye technique	NPV—57% PPV—91% Medial wall; Se—56%, Sp—95%, Ac—90%, PPV—71%, NPV—91% Lateral wall; Se—92%, Sp—88%, Ac—90%, PPV—92%, NPV—88%
S11	Jank et al.[18] (2004)	Prospective	Not controlled	60	Infraorbital rims	CT	7.5 MHz, curved closed eye technique	Infraorbital rim; Se—94%, Sp—92%, Ac—92%, PPV—91%, NPV—92% Orbital floor; Se—95%, Sp—100%, Ac—98%, PPV—100%, NPV—77%
S12	Jank et al.[15] (2006)	Prospective	Not controlled	28	Orbital fractures	CT	7.5 MHz, curved closed eye technique	Inferior orbital margin; Se—86%, Sp—94%, Ac—90%, PPV—92%, NPV—89% Orbital floor; Se—90%, Sp—100%, Ac—94%, PPV—100%, NPV—60% Medial wall; Se—89%, Sp—91%, Ac—90%, PPV—80%, NPV—95% Lateral wall; Se—93%, Sp—87%, Ac—90%, PPV—88%, NPV—93%
S13	Jank et al.[15] (2006)	Prospective,	Not controlled double blind	13	Medial and lateral	CT	7.5 MHz, curved closed eye technique	Medial wall; Se—100%, Sp—90%, Ac—92%, PPV—75%, NPV—100%
					Orbital walls			Lateral wall; Se—88%, Sp—94%, Ac—92%, PPV—88%, NPV—94%
S14	Hong et al.[12] (2007)	Cross-sectional	Not controlled	26	Nasal bone	CT, conventional X-ray	7–15 MHz hockey stick	Ac—100%
S15	Blessmann et al.[3] (2007)	Cross-sectional, single blind	Controlled	10	Midfacial fractures	CT	8 MHz for orbital	Poor correlation for isolated orbit floor and undisplaced zygomatic arch
							12 MHz for others Linear	Good correlation for medial and lateral orbital walls, anterior wall of maxilla and displaced zygomatic arch
S16	Muhammadi et al.[26] (2009)	Cross-sectional double blind	Not controlled	171	Nasal bone	Convention X-ray	10 MHz, linear	Se—90%, Sp—98%, PPV—98%, NPV—87%
S17	Lee et al.[24] (2009)	Cross-sectional double blind	Not controlled	138	Nasal bone	Conventional X-ray CT	High resolution US	Se—100%
							10–15 MHz hockey stick	Sp—100%
								Ac—100%

Se—sensitivity; Sp—specificity; Ac—accuracy; NPV—negative predictive value; PPV—positive predictive value.

Table 2. Limitations of diagnostic ultrasonography in maxillofacial fractures.

Limitations	Studies in which it was noted[1]
Inability to delineate complex multiple facial fractures	S17, S14, S8
Inability to distinguish new fracture from old fractures	S14
Confusion of some anatomical areas as fractures	S14
Difficulty in detecting non dislocated fractures	S10, S7. S8, S15
Difficulty in imaging of posterior aspect of the orbital floor	S1, S2, S8
Detailed bony imaging may be precluded in acute situations with extensive facial oedema, and emphysema	S6, S8
Unable to identify intracapsular fracture of mandibular condyle due to overlapping of zygomatic arch	S7

[1]See Table 1 for allocation of study numbers.

Table 3. Factors affecting validity of diagnostic ultrasonography in maxillofacial fractures.

1. Experience of sonographer
2. Type and resolution of transducer
3. Lack of standard scanning technique for the facial skeleton
4. Real time visualization is better than interpretation of hard copy
5. Timing of the sonographic investigation from the time of injury.

of superficial structures of the head and neck and was thought to have a limited role in bony lesions[32]. Following improvements in ultrasound technology and the advent of high resolution ultrasonography, it is now being used routinely in the examination and diagnosis of bone pathology[1].

The relative merits of ultrasonography are considerable. Ultrasound facilities are widely available, even at the lowest level of health care[15,17,18]. The cost of investigation is comparatively cheap, it is less dependent on patient cooperation and the technical sensitivity of patient positioning is minimal[6,22]. Ultrasonographic imaging can be done in real-time, allowing dynamic and three-dimensional imaging[22]. The equipment is portable enough to be moved into the operating room for intraoperative imaging and the evaluation of fracture reduction[2,22]. The risk associated with radiation exposure is excluded, so imaging can be repeated several times without any major concern[6,22].

Ultrasonography was first used as a diagnostic tool for maxillofacial fractures in 1981 when Ord et al[27]. used it to detect orbital wall fractures. Since then, several authors have reported their experiences[2,6,14–20,22]. There has been no attempt to encapsulate the evidence from the various studies in a systematic review or meta-analysis.

Traditional literature reviews are conducted, using expert opinion to define the questions and to select and summarize evidence[31]. Unlike traditional reviews, systematic reviews are conducted using set criteria to search for evidence, critically appraising the evidence on the basis of methodology and validity of results, and summarizing the evidence to provide salient information transferable to clinical practice[31]. In this systematic review, a pool of evidence supporting the use of ultrasound in the diagnosis of different types of facial fractures was identified.

The most useful diagnostic tests help to establish an accurate diagnosis that supports the most appropriate treatment leading to the best outcome for the patient[31]. The best tests have high sensitivity and specificity. When assessing a diagnostic test, it must be compared blindly and independently with a gold standard[31]. In the articles available for this review, ultrasonography was compared with CT or conventional plain radiograph or intraoperative observation of the fracture or combinations of the methods.

Ultrasonography has shown very high accuracy for the detection of nasal bone fractures with sensitivity ranging from 90% to 100%, specificity of 98–100% and high predictive values[12,24,26]. This finding was supported by the reports of Friedrich et al.[7] and Hirai et al.[11] thus establishing that ultrasonography is an adequate investigation for clinically suspected isolated nasal fracture. It was found to be better than CT in the studies of Lee et al.[24] and Hong et al.[12] in which it was able to detect linear non-depressed fractures of the nasal bridge and anterior septal cartilage deviation, which were missed by CT scanning.

Orbital fractures are the most extensively investigated maxillofacial fractures with the aid of ultrasonography[6,14–19]. Medial and lateral wall and orbital floor fractures are the most investigated orbital wall fractures. Little work has been reported on orbital roof fractures. The least sensitivity observed for detection of medial and lateral wall fractures was 56% and 88%, respectively[13,15], whilst the least specificity was 90% and 87%, respectively[14,15]. Generally, accuracy for detection of orbital wall fractures was 90–100%[6,14,15,16]. These support the clinical reliability of ultrasound imaging in the diagnosis of these fractures. In the case of the orbital floor, sensitivity and specificity ranged from 85% to 100% and 57% to 100%, respectively, and accuracy was 86–98%[16,17,19,25]. It was consistently observed that orbital floor fractures beyond 4 cm posterior to the orbital margin is poorly detected by ultrasound[7,25].

Fractures of the inferior orbital rim are readily detected by ultrasonography with sensitivity and specificity up to 94% and 92%, respectively[16]. Infraorbital orbital rim fracture often occurs as part of zygomatico-maxillary or zygomatico-orbital fractures. Ultrasonography has been reported to readily detect fractures of the anterior wall of the maxilla[3,7,25]. The use of diagnostic ultrasonography in zygomatic arch fractures has been well investigated and it is found very accurate in all cases of displaced arch fractures[25]. A few other studies[3,10] support this finding but were not included in the present review for failing to meet the inclusion criteria.

Only a few authors have investigated the use of ultrasound in mandibular fractures. This is probably because mandibular fractures are easily diagnosed by clinical examination and conventional radiography. Hirai et al.[11] in their case series demonstrated that ultrasound readily detects fractures of the mandibular symphysis and angle. Advanced radiological investigations are sometimes indicated in cases of subcondylar fractures of the mandible. This is one area where the use of ultrasound might be necessary in the management of mandibular fractures. Kleinheinz et al.[20] and Friedrich et al.[8] reported ultrasonographic sensitivity and specificity of 100% and 100%, respectively, and 66% and 52%, respectively, in the detection of mandibular subcondylar/ramus fractures. Friedrich et al.[8] emphasized the limitation of ultrasound as failure to detect intracapsular condylar fractures due to the overlap of the zygomatic arch[7]. Although, the current findings are promising, further investigation is required to document strong evidence on the appropriateness of diagnostic ultrasonography in mandibular fractures.

Table 2 highlighted some of the notable limitations of ultrasonography in the diagnosis of maxillofacial fractures. Ultrasonography may not be sufficient to diagnose complex maxillofacial fractures, such Le Fort fractures and multiple or pan facial fractures, and the use of CT in such cases is obligatory. Ultrasound poorly detects non-displaced fractures of most facial bones and in the acute situation, proper imaging may be precluded by massive inflammatory oedema and emphysema as well as pain and tenderness elicited during probing. It may be advisable to delay ultrasonographic examination until about 72 h post-trauma in nonemergency situations.

Chiappelli and Cajulis[4] emphasized the need to take evidence-based clinical practice beyond academic exercise, and to focus on 'Patient Oriented Evidence that Matters (POEM)'. They cautioned that all patient oriented evidence is not to be blindly applied but should be subjected to 'Research Evaluation and Appraisal by the principles of evidence-based Dentistry (READ)'. They coined the slogan, 'POEM is good only as long as we READ'. Following this principle, it is important not to embrace the evidence supporting the use and probably the substitution of ultrasonography for conventional radiography and CT in maxillofacial trauma diagnosis just because it is patient oriented, but also to appraise the sources of the evidence. Hence, the authors set up limiting criteria and critically appraised the study designs and methodology of the studies reviewed. They observed that all the studies (except one case series) were based on prospective or cross-sectional studies. Observer blinding was adopted in five studies and controls introduced in four. This implies that the current evidence is essentially at middle to high level in the hierarchy of evidence[30]. In fact, prospective, cohort/cross-sectional studies have been noted to be most appropriate for investigating the diagnostic value of a clinical tool[30].

Internal validity was assessed by ensuring uniformity of technique in individual study and tests carried out by the same or calibrated investigators with blinding of investigators in some studies. Sonographic techniques, transducer types and frequency as well as expertise of sonographer differ between studies, so it was difficult to assess the external validity of the projected evidence but the consistency of the findings in the studies suggests the validity of the evidence.

Some of the factors affecting the validity of diagnostic ultrasonography in maxillofacial fractures are itemized in Table 3. These include the experience of the sonographer and the type and resolution of the transducer. There is need for a standard sonographic technique for maxillofacial imaging. The use of regular linear probes leads to problems with poor adaptation to facial topography; some investigators overcame this by using curvilinear and small size probes. Specially designed transducers suited to maxillofacial topography are desirable. Real-time sonographic imaging is the best technique for maximizing the benefits of diagnostic ultrasound in maxillofacial fractures. This enables dynamic visualization of the facial skeleton in three dimensions and forestalls the need to depend on a hard copy of the ultrasound image, which is often more difficult to interpret. This underlines the need for craniomaxillofacial trauma surgeons to be trained in ultrasonographic techniques so that real-time imaging can be done intraoperatively.

In conclusion, a high level of evidence is available to justify the use of diagnostic ultrasonography in maxillofacial fractures. Nasal bone fractures, orbital fractures, anterior maxillary wall and zygomatic arch fractures are readily detected. Ultrasonography is also promising in the detection of extracapsular subcondylar fractures, but the clinician must appreciate its limitations in undisplaced fractures, complex maxillofacial fractures, posterior orbital floor fractures and intracapsular mandibular condyle fractures. The need to develop standard sonographic techniques and design special transducer probes has been highlighted. It is also important for craniomaxillofacial trauma surgeons to be trained in the use of ultrasound. Ultrasonography holds greater promise in maxillofacial trauma care, both in diagnosis and treatment. If properly developed and deployed, the relative advantages of ultrasonography over CT could relegate the use of CT to exclusive situations and so revolutionize maxillofacial imaging in trauma care.

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None declared.

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