Applications of Ultrasonographic imaging in dentomaxillofacial region. A narrative review

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KEYWORDS

Color Doppler Ultrasonography, Diagnostic imaging, Elastography, Transducer, Ultrasonography.

ABSTRACT

Aim: *The aim of this narrative review is to explore various applications of USG imaging in the dentomaxillofacial region.*
Methods: *A search was performed on various databases and platforms including PUBMED, Scopus, Ebscohost, Google Scholar, Science Direct etc.*
Results: *The story of application of Ultrasonography (USG) in imaging goes back a long way in history. Strictly speaking, the term Ultrasound (US) refers to acoustic waves which correspond to the upper limit of sounds audible to humans (>20 KHz), whereas the USG refers to the use of an Ultrasound for diagnostic purpose. It has been deemed useful in various situations and has evolved over time to a more sophisticated and precise modality. Some of the advances are in the form of newer and more useful equipment increasing its pertinence in dentistry and medicine. Currently it is being used in various head and neck pathologies owing to its non-invasive nature and has gained a wider acceptance in maxillofacial imaging. Applications of USG imaging particularly in dentomaxillofacial region include head and neck pathologies, examination of bone and superficial soft tissue, detection of major salivary gland lesions, temporomandibular joint imaging, implant imaging, assessment of fractures and vascular lesions, lymph node examination, measurement of the thickness of muscles and visualization of vessels of the neck.*
Conclusion: *USG has the potential to be used in the evaluation of periapical lesions and follow up of periapical bone healing.*

Introduction

Imaging forms the corner stone of accurate diagnosis and formulation of treatment plan. With novel advancements in this field, the existing modalities are successfully redefining the rules of diagnostic imaging. The terms sonogram and US are used interchangeably. However, there is a difference between the two: An ultrasound is a tool used to take a picture. A sonogram is the picture that the ultrasound generates. The USG is the use of an ultrasound tool for diagnostic purposes (1).

In diagnostic USG, high frequency sound waves (>20 KHz), are transmitted into the body by use of a transducer and echos from tissue interface are detected and displayed on a screen (2, 3). Sound waves are emitted via piezoelectric crystals from the ultrasound transducer. Piezoelectric crystals are constructed from material that converts electrical signals into mechanical vibrations and vice versa (4, 5).

The piezoelectric system is based on the principle that quartz is subject to a change in shape when placed within an electrical field (6). The main component of the transducer is a thin piezoelectric crystal or material made up of a great number of dipoles - distorted molecules that have a positive charge on one end and a negative charge on the other - arranged in a geometric pattern. Currently the most widely used piezoelectric material is lead zirconate titanate (7). USG continues to gain popularity due to its non-invasive nature, easy availability and relative cost effectiveness. Furthermore, it gives “real-time” tomographic images with cross sectional information (8).

Acoustic impedance is the term used to define the resistance of a material to propagation of ultrasound waves. It depends on the density of the material. If the material is solid, the particles are denser and sonographic waves are reflected more. Therefore, solid material transmits fewer sound waves than fluids and less ultrasound waves are reflected back from fluids. As a result, an echogenic "black" image is produced. Stones and bones reflect more sound waves than fluid and they produce "white" bright images. Since ultrasound waves cannot transmit through stones, a black acoustic shadow is present behind them. Air is a robust ultrasound beam reflector which makes it difficult to visualize structures (4).

Advantages of USG

USG is a dynamic technique and useful in evaluation of soft tissue structures. Most importantly, it is non-invasive, does not use radiation and provides real-time images. Hence, the patient compliance is excellent. There are fewer occurrences of artifacts and since the influx of state-of-the-art technologies, the design of the USG has improved manifold. USG is now available in a compact form for clinical use.

USG is also an alternative diagnostic method for the imaging of temporomandibular disorders owing to satisfactory and promising results obtained from high resolution USG in the assessment of temporomandibular joint (TMJ). It is harmless, fast, comfortable, economic and available in most centers. With the aid of resolution transducer, USG can demonstrate the internal muscle structures clearer than computed tomography (CT).

Furthermore, USG is the only available imaging technique that can be used for frequent routine follow-ups of cervical lymph node metastases (9, 10). USG guided core needle biopsy is recommended as a safe and reliable technique in the diagnosis of cervico-facial masses with a high diagnostic yield (11, 12). The application of USG in midfacial injuries is most useful for the visualization of the zygomatic arch when immediate imaging is performed after closed reduction. USG can be considered as the imaging of choice when there is a contraindication to CT or plain films (for example, in pregnant women, patients with cervical spine injuries and bone fracture) (13, 14, 15).

Disadvantages of USG

USG is still highly operator-dependent and hinges a great deal on the experience and knowledge of the operator. Since, specific reproducible scan planes are not available for USG, the images are difficult to orient and interpret. The images also suffer from anatomic noise accompanying the inherent noise due to the signal returned to the transducer which makes interpretation of the static and dynamic images challenging (8).

US waves can damage tissues at high exposure levels, in addition to having teratogenic effects, due to heat, and acoustic cavitation. In addition, metallic implants, dental fillings and restorations may cause blurring of the image due to artefacts generated by the metal (16).

It is difficult to visualize the articular disk with USG when it is placed between two hard tissue structures. Therefore, imaging disk position by using USG is difficult (16). Finally, in the case of acute conditions with facial edema and empyema, bone visualization may be complicated (16).

The features and utility of USG are comparable with those of other modalities like CT (Computed Tomography) and MRI (Magnetic Resonance Imaging) (8, 17, 18) (Table 1).

Imaging technique	Advantages	Demerits	Radiation dose (mSv)
USG	Useful for evaluation of soft tissues, real-time images, non-ionizing radiation, non-invasive, painless with good patient compliance, easy availably, less expensive, artifacts are uncommon	Operator dependent compromised quality of image owing to insufficient contrast and resolution	None
CT	Superior geometric resolution 3D imaging provides cross-sectional information, critical structures can be visualized accurately	Streak artifacts in axial and coronal sections thus reformatted thin-slice axial CT preferred, motion artifacts, high cost and radiation dose	2 mSv for head CT
MRI	Excellent evaluation of soft tissues helps recognize and differentiate critical anatomical structures, e.g.: Neurovascular bundle from adjacent trabecular bone	Bony detail cannot be appreciated, magnetic field strength >3 Tesla causes heating of tissues. Ferromagnetic alloys produce geometric distortion	None

Table 1 The paper analyzed

How to differentiate between normal and abnormal USG images?

The US signal transmitted into a patient is attenuated by a combination of absorption, reflection, refraction, and diffusion. The higher the frequency of the sound waves, the higher the image resolution but lesser penetration of the sound through soft tissue. The fraction of the beam that is reflected to the transducer depends on the acoustic impedance of the tissue, which is a product of its density (and thus the velocity of sound through it) and the beam's angle of incidence. Because of its acoustic impedance, a tissue has a characteristic internal echo pattern. Consequently, not only can changes in echo patterns distinguish between different tissues and boundaries but they also can be correlated with pathologic changes within a tissue. Tissues that do not produce signals, such as fluid-filled cysts, are said to be anechoic and appear black. Tissues that produce a weak signal are hypoechoic, whereas those that produce intense signals such as ligaments, skin, or needles, or catheters are hyperechoic and appear bright (19).

Methods

In the present article, the authors propose a narrative review of USG and its applications pertaining to dentomaxillofacial region. The authors mention about various pathologies in the head and neck region and their image viewing using USG. The authors mention various studies conducted specifically for applications of USG in the head and neck regions. The references are collected from various databases and platforms that includes PUBMED, Scopus, Ebscohost, Google Scholar, Science Direct etc.

Search keywords were the following: Ultrasonography, Dentistry, Radiology, Dentomaxillofacial radiology; Salivary gland neoplasms, Biopsy, large-core needle, Biopsy, fine-needle, Parotid gland, Submandibular gland; Color; doppler; magnetic resonance imaging; salivary gland neoplasms; ultrasonography.

Applications of USG in maxillofacial imaging

Imaging of structures in head and neck can be performed with exquisite details using USG.

1) Swellings of head and neck region

USG can be used in establishing differential diagnosis of cystic or solid masses of the neck, cervical lymphadenopathy. It serves to differentiate benign from malignant masses and intraglandular and extraglandular anomalies of the salivary glands.

Inflammatory swellings: Sigert et al. had initially classified the USG appearances of inflammatory swellings into five types: edema, infiltrate, pre-abscess, echo-poor abscess and echo-free abscess (20, 21).

Cystic swellings: Cysts appear as anechoic areas due to their fluid/air filled nature. Since liquids are homogeneous and there are no structures to produce internal echoes, there is little or no attenuation of sound, which creates enhanced transmission of sound at the distal aspect of cystic mass. If the cyst becomes infected then the content of the lesion can produce some echoes leading to a hypoechoic area. For example, branchial cyst and sebaceous cyst classically appear as well defined, homogenous, anechoic and hypoechoic areas respectively with posterior acoustic enhancement (20).

Benign Neoplasms: Pleomorphic adenoma appears as rounded, circumscribed and hypoechoic, with distal acoustic enhancement. Lipomas are seen as oval or elliptical masses with regular margins and a typical striped or feathered internal echotexture. Haemangiomas appear as multiple hypoechoic areas with some amount of vascularity on doppler study (20).

Malignant neoplasms: The USG features depend on the grade of the tumor. Low-grade malignant neoplasms appear similar to pleomorphic adenoma and larger lesions present with apparent malignant features like irregular, poorly defined margins and heterogeneous internal structure (20).

A study conducted by Shankar et al. established the reliability and diagnostic efficiency of USG in head and neck swellings (20). The sensitivity and specificity of USG in inflammatory swellings was found to be 96.5% and for cystic swellings, swellings of muscular origin, lymphadenopathies, it was 100%. In addition, sensitivity and specificity for benign and malignant neoplasms was 92.86% and 100% respectively (20). Specific appearances were noted for different swellings. An abscess appears as an ill-defined hypoechoic area. Submandibular sialadenitis was seen as duct dilation proximal to an obstruction. Acute parotitis was seen as an enlarged hypoechoic gland with coarsening of gland texture and chronic parotitis presented as a coarse, reticulated pattern with multiple, rounded, hypoechoic foci seen within the gland parenchyma (20, 22) (Table 2).

Reference	Sample size	Method	Accuracy (%)
Song H et al. (45)	228 USG 371 FNAC	Histo-pathology	88.20 58.20
Davachi et al.(46)	22	MRI	95
Freed et al. (47)	35	CT	89
Kraft et al. (48)	104	Histo-pathology	99

Table 2 Showing comparison of different studies conducted in order to assess salivary gland tumors with USG (16)

2) Oral Submucous Fibrosis (OSMF)

USG imaging can be used to demonstrate number, length and thickness of the fibrotic band (23) OSMF shows increased hyperechoic areas representing fibrous bands or diffuse fibrosis. Color Doppler and Spectral Doppler show decreased vascularity and peak systolic velocity (PSV) in lesional area (23). Masticatory muscle hypertrophy is also seen in OSMF patients which can be assessed with USG. Chakravarti et al. measured the thickness of masseter muscle by USG (5-11mHz) and found it to be increased in OSMF as compared to a control group. Also, thickness was more during contraction as compared to relaxation in both OSMF patients and normal individuals (24).

Krithika C. et al. characterized the USG features of the buccal mucosa in patients with OSMF and observed that the submucosa which appeared hypoechoic in the control group had a significantly increased echogenicity in the case group. Hence, concluding that increased submucosal echogenicity and reduced echo differentiation was present between submucosa and muscle layer in OSMF cases (25).

Correlation of Submucosal Thickness in OSMF cases and in controls: The most important parameters describing the interactions between US and the tissue through which it is transmitted are attenuation, velocity and impedance. The attenuation and velocity increase in proportion to the relative amounts of collagen in the tissue. On the other hand, they decrease in relation to the increase in water content. Collagen has a greater modulus of elasticity than other tissues. This leads to a higher velocity and higher impedance and for this reason collagen is one of the main sources of echogenicity. As there is increase in the collagen fibres in OSMF this could be the most possible reason of increase echogenicity and increased submucosal thickness in USG (26).

OSMF management by USG technique: USG proves to be an efficient deep heating modality. It increases the temperature of buccal mucosa due to its absorption by the tissue proteins that converts the ultrasonic waves into heat. It has been found that heating the tendon in combination with low load, prolonged stretch produce the greatest elongation with least damage to the tissue. Thus, if US is applied at a higher intensity for a longer duration, a higher tissue temperature is attained. Heating the tissues in combination with exercises causes loosening and softening of adherent fibrous tissues by separation of collagen fibers and thus leads to the increased pliability of oral mucosa and improves mouth opening (27).

3) Salivary Gland Ultrasonography (SGUS)

Various parameters that can be studied using USG include salivary gland volume, degree of homogeneity (homogeneous, non-homogeneous) and echogenicity (isoechoic or hypoechoic). A structurally normal salivary gland has a medium gray scale homogeneous echo pattern and the level of echogenicity is higher than that of the surrounding muscles.

SGUS studies can be used to differentiate inflammatory, cystic or neoplastic swellings of salivary glands (21). Salivary gland obstruction presenting with pain and swelling is found to be commonly associated with sialoliths or strictures. Sialoliths within the gland parenchyma or the duct appear as intense hyperechoic foci with distal acoustic shadowing, except for small stones (<2mm) that present without a shadow. The duct proximal to the stone sometimes shows visible dilatation and even radiolucent sialolith can be visualized using USG (20, 22).

SGUS also has been used for diagnosing primary Sjögren syndrome (SS). Cornec et al. studied the echo structure of the parotid and submandibular glands bilaterally and graded it from 0 to 4. The gland size was measured and blood flow to the parotid gland was calculated using Doppler study. Based on their findings they concluded that the addition of SGUS to the American European Consensus Group (AECG) classification criteria for SS increased the sensitivity to 87.0% (28).

Obinata et al. compared sialography, histopathology and USG for the diagnosis of SS. The sensitivity was 83.3% for sialography, 77.8% for US, and 63.9% for histopathology (29).

4) Cervical Lymph Node Assessment

Preoperative USG imaging, plays an important role in delineating the surgical treatment plan in malignancies. Normally, lymph node appears as a homogeneous hypoechoic area with a thin cortex and shows hilar vascularity or largely avascular areas in Color Doppler mode (26, 27) Reactive lymph nodes are hypoechoic with or without the presence of echogenic hilus whereas neoplastic nodes have indefinite internal or hilar echoes (20).

In a study by Hwang et al., the sensitivity and specificity of USG in predicting papillary thyroid carcinoma metastasis in the central neck was estimated to be 30.0% and 86.8%, respectively and in the lateral neck 93.8% and 80.0%, respectively (30). Another study by Kawaga et al. quantitatively evaluated the relationship between vascularity within lymph nodes and lymph node size on Doppler USG images of patients with oral cancer. The authors conclude that an increase in vascularity was a characteristic Doppler USG finding in small metastatic lymph nodes and as the size increased, blood flow signals got scattered and the scattering index increased (31).

5) Temporomandibular Disorders (TMDs)

High Resolution Ultrasonography (HRUS) that shows "real-time" images of articular disc during the mouth opening has been used in evaluation of TMDs. USG image of the disc is of a thin homogenous, hypo/isoechoic band whereas mandibular condyle and the articular eminence are appreciated as hyperdense lines (32, 33).

In closed mouth position, intermediate zone of the disc rests between the anterosuperior aspect of the condyle and the posteroinferior aspect of the articular eminence. When located anterior to this position, disc is regarded as anteriorly displaced. In open mouth position, normalcy is defined by intermediate zone located between the condyle and the articular eminence (32, 34). Razek et al. assessed the pattern of articular disc displacement in patients with internal derangement using USG and concluded that the diagnostic efficacy of USG for anterior displacement has sensitivity of 79.3% and specificity of 72.7% (35).

Therapeutic USG utilizes high frequency waves for decreasing pain and swelling for improving the circulation of TMJ. Major studies and literature proposes that USG therapy alone is not sufficient for TMDs and suggested that use of electrophysical mode of therapy in the early stages of disease is very potential in alleviating the symptoms (36).

USG can demonstrate the internal muscle structures more clearly than CT. It can also measure the thickness of muscles which can be an important tool in diagnosis and treatment for follow-up examination of inflammatory soft tissue conditions of the head and neck region and superficial tissue disorders of the maxillofacial region (36).

6) Other applications of ultrasound

Periapical and intraosseous lesions, maxillofacial trauma, detection of foreign bodies, USG guided fine needle biopsy, submandibular gland injection of botulinum toxin for hypersalivation in cerebral palsy and in basket retrieval of salivary stones (16).

Color Doppler USG has also gained popularity in diagnosis of vascular anomalies of head and neck by obviating the need for biopsies and decreasing the associated risks. It can be used in imaging of vascular tumors like hemangiomas, lymphangiomas or slow-flow and high-flow vascular malformations (38). A common Color Doppler presentation of arteriovenous malformation of tongue is described as a hypoechoic area with lobulated margins with the depiction of feeder vessels as well (37). The USG here serves not only as a diagnostic procedure but provides treatment guidance as well.

Oral cancer tumor thickness

Wakasugi Sato et al. developed a method in order to allow operators to easily assess and confirm the surgical clearance of tongue carcinomas intraoperatively using intraoral US. Tumor thickness was reported as an important prognostic factor in cancers of the oral cavity. Authors demonstrated that there was a strong correlation between tumor thickness measured from ultrasonic images and histological sections (38).

Shintani et al. measured tumor thickness of squamous cell carcinoma and compared the clinical usefulness of CT, MRI, and intraoral USG to delineate the extent of tumors. They showed that intraoral US is very accurate and valuable for mapping these tumors (39).

Mid-face fractures

There are some inherent disadvantages of CT scan, such as the patient's exposure to a high dose of radiation and the potential risk of developing cataracts limit its use in many patients, such as pregnant women and children. It is also too expensive and time-consuming to use in isolated simple fractures. In contrast, there are several advantages to using USG, such as "no radiation exposure, inexpensive, non-invasive, portable, readily available and fast, but has to be performed by experienced investigators". Considering the advantages, USG can be a potential alternative to conventional radiography. There are several studies which were conducted in order to assess the versatility of USG for midfacial fracture diagnosis in trauma cases. USG, however, cannot penetrate deeper bony structures, and hence, its use is currently restricted to the evaluation of superficial facial structures.

Authors of a study used USG in diagnosing zygomatico-orbital complex fractures and found an accuracy of 94% (40).

In one study, of the total 440 sites examined, 84 sites were found to be fractured according to the gold standard CT scan examination. When compared to CT scan, USG evaluation of all fracture sites together showed a sensitivity of 83.33% and a specificity of 98.88 (41).

According to Blessmann et al., by using USG the zygomatic arch could be visualized quite reliably whereas assessment of the orbital floor proved to be rather difficult. Soft tissue covering of the tissues impairs imaging of fractures in several planes. Therefore, the application of USG is not a substitute for accurately taken X-ray imaging for detecting fractures of the mandibular ramus and condyle (42) (Table 3).

Sjogren's syndrome

Primary Sjogren's syndrome (PSS) is a chronic autoimmune condition affecting the exocrine glands. Study conducted by Kazzak B.A. et al. indicate that

Reference	Design	Sample size	Fracture	Method	Accuracy
Nemati S. et al. (49)	Single blind	37	Nasal bone	Physical method	100%
Ogunmuyiwa et al. (50)	Prospective	21	Zygomatic complex fractures	CT	100%
Javadrashid et al. (51)	Cross sectional	40	Nasal bone	CT	94.90%
Jank et al. (52)	Prospective	13	Orbital	CT	92% medial wall, 88% lateral wall

Table 3 Types of articles published

USG findings have a high specificity for PSS. The authors observed the relation between USG findings and severity of dryness symptoms, exocrine function glandular inflammation and systemic autoantibodies. The results of the above study suggested that USG is an effective tool for assessing salivary gland involvement in PSS (43).

USG in implant imaging

USG may play an important role in locating submerged implants. The study conducted by Marroti J. et al. reported that a new ultrasonic device including a soft tissue matched transducer with a customized trans receiver and signal processing was capable of measuring soft tissue thickness over bone and implants placed in porcine models (44). The authors of the above mentioned study, suggested that this new ultrasound device was efficient as a diagnostic tool for intraoral measurements of the inferior alveolar canal and floor of the maxillary sinus before dental implant placement owing to its non ionizing nature (44).

Conclusion

In the past few years, USG has expanded its horizons in maxillofacial imaging. The sensitivity and specificity of USG has been proved to an acceptable degree in different situations thus, reinstating the position of USG as the imaging modality of choice in a number of clinically perplexing entities. Although concomitant limitations did exist with USG they have been largely overcome with modifications in the apparatus and machine. USG is a continuously progressing technology and further research should be focused on its clinical applications in the maxillofacial region.

Future perspective

At present, scientific literature has very less clinical evidence related to therapeutic utility of US, therefore it would be impulsive to abandon the use of USG for diagnostic therapeutic purposes. Today, we are in need of more studies that must emphasis to study the bio-effects of USG in more comprehensive manner and provide reliable method which can be reproducible for its better performance As it is relatively inexpensive, noninvasive method where in non ionizing radiation has been used which makes it as readily available and provides both static and dynamic images. Hence, the use of ultrasound will continue to increase and definitely has better scope in the future.

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