REVIEW ARTICLE

Ultrasound in maxillofacial imaging: A review
Chaya M. David, Ritu Tiwari

Department of Oral Medicine and Radiology, Dayananda Sagar College of Dental Sciences and Hospital, Shavige Malleswara Hills, Bangalore, Karnataka, India

Abstract
The story of the application of ultrasound (US) in imaging goes back a long way in history. 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 wider acceptance in maxillofacial imaging. In this paper we will take a relook of US in areas such as its history, basic principles, advances in the equipment and wide array of applications in head and neck pathologies and also weigh its merits and demerits in specific areas.

Keywords
Color Doppler ultrasonography, elastography, transducer, ultrasonography

Introduction
Imaging forms the cornerstone of accurate diagnosis and formulation of the treatment plan. With novel advancements in this field, the existing modalities are successfully redefining the rules of diagnostic imaging. Ultrasound (US) is one such modality which has grown by leaps and bound. Strictly speaking, the term refers to the acoustic waves which corresponds to the upper limit of sounds audible to humans (>20 KHz). Over the past few decades, rapid strides in technology have led to the emergence of an array of applications in the maxillofacial area. The latest generation of machines and different sizes of transducers suited for head and neck region have provided enhanced spatial resolution and excellent near field resolution. There has been a great deal of interest in the imaging of neoplasms in the thyroid, salivary gland, the floor of mouth, tongue, and palatal tumors. It can also be used to assess the acoustic waves which corresponds to the upper limit of sounds audible to humans (>20 KHz). Over the past few decades, rapid strides in technology have led to the emergence of an array of applications in the maxillofacial area. The latest generation of machines and different sizes of transducers suited for head and neck region have provided enhanced spatial resolution and excellent near field resolution. There has been a great deal of interest in the imaging of neoplasms in the thyroid, salivary gland, the floor of mouth, tongue, and palatal tumors. It can also be used to assess the lymph nodes, tumor thickness (TT), sialoliths and in the examination of vessels of the neck like atherosclerotic plaques in the carotid artery. Other important applications being US guided fine needle aspiration biopsy, temporomandibular joint disorders (TMDs), and masticatory muscle assessment.

The US 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.

Despite this, US often have faced criticism due to its high operator dependence and poor contrast. However, with the advent of novel improved versions of equipment, color-Doppler and three-dimensional (3D) US these limitations have been overcome to a large extent. This article revisits the evolution of US along with its basic principles and equipment while highlighting the notable advances made in the technique and its various contributions in diagnostic maxillofacial imaging.

History
The first recorded evidence referring to the use of sound waves for the spatial orientation in bats dates back to 1794 by Lazaro Spallanzani, who discovered the phenomenon of echo-location. Not long after that, in 1877, Jacques, and Pierre Curie described the piezoelectric and the inverse piezoelectric effect. This path-breaking discovery led to the conceptualization of ultrasonography.

Ian Donald introduced the US in diagnostic medicine in 1956, when he used one-dimensional Amplitude mode (A-mode) to measure the fetal head. The commercial use of US devices began in 1963 when “brightness mode” (B-mode) devices were constructed. In 1955, Satomura and Nimura were credited for Doppler effect based visualization of blood circulation. What
followed was the “Sonic Boom” of the 1970s, when the “gray scale” was introduced that lead to the introduction of US scanners that generated the real time images. The first use of diagnostic US in dentistry appears to have been by Baum et al. in 1963, to image the internal structures of teeth using 15 MHz wave.\textsuperscript{[5]} The clinical applications in dentistry were studied actively afterward, the most noteworthy being the work of Palou et al. (1987) in the measurement of periodontal bone morphology.\textsuperscript{[6]}

The late 1990s to early 2000 saw an expanded the research focusing on the dental hard tissues and soft tissues. Hinders and co-workers (1998) developed the US periodontal probe at NASA Langley Research Center.\textsuperscript{[6]} Culjat et al. (2003) used pulsed US imaging to determine the enamel thickness.\textsuperscript{[9]} Current research endeavors at expanding the usage of US in maxillofacial region, some of them directed in detection of caries, dental cracks and fractures, soft tissue lesions, periapical lesions, maxillofacial fractures, muscle thickness, and implant dentistry.\textsuperscript{[10]}

\textbf{Basic Principles and Equipments in US}

Ultrasonography is founded on the principle of conversion of electric energy to mechanical energy and viz.\textsuperscript{[11]}

The US is a longitudinal pressure wave made of areas of compression and rarefaction. When transmitted through a medium, it causes the molecules to oscillate in the course of wave propagation.\textsuperscript{[12]} Simplest manner of depicting a US beam is in the form of a parallel bundle for a certain distance beyond which it disperses. This parallel component is referred to as the Fresnel zone (near-field) and diverging portion is called the Fraunhofer zone (far-field) [Figure 1]. Pressure amplitude varies greatly in the Fresnel zone, and it decreases at a steady rate with the increasing distance from the transducer in the Fraunhofer zone.\textsuperscript{[11]} The high-frequency US has a long Fresnal zone and a greater depth resolution, although the tissue absorption also increases.\textsuperscript{[13]}

US pulse comprises a collection of frequencies called the bandwidth (5-20 MHz). Higher is the fundamental frequency, better is said to be the spatial resolution. As the wave passes through the tissues, it speeds up during the compression phase and slows in rarefaction phase. This produces distortion and creates the harmonic frequencies. Harmonics are those frequencies which are the multiples of fundamental frequency. Echoes from the patient being a mirror image of the pulse, also have the same distortion and harmonic frequencies.\textsuperscript{[14]}

The Diagnostic US utilizes a transducer for conversion of energy, built on the phenomenon of piezoelectricity. The piezoelectric effect is a reversible process in which crystals (lead zirconium titanate) exhibiting the direct effect and the reverse effect that is, the generation of electrical charge from an applied mechanical force and vice versa. When an external electric impulse is sent to these crystals, their dipoles align themselves in accordance with the electric field leading to a change in the thickness of the crystal. This begins a series of vibrations that produce the sound waves which are transmitted into the tissues.\textsuperscript{[3]}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{ultrasound_beam.png}
\caption{Ultrasound beam showing Fresnel and Fraunhofer zone}
\end{figure}

The transducer functions as both “transmitter” and “receiver” and obtains the beam reflected from the tissues.\textsuperscript{[12,15]} It detects and amplifies the weak signals and compresses the wide range of amplitudes into a range that can be displayed on the screen.\textsuperscript{[14]} Each transducer is focused at a particular depth.\textsuperscript{[14]} The echoes so established collectively form an image that can be visualized and documented.\textsuperscript{[12,15]} The image displayed comprises of a wide gray scale depending on the echogenicity of the tissue imaged. Echogenicity is the ability of a surface to return a signal. Structures are said to be hyperechoic, when they are brighter than their surroundings, hypoechoic structures are less bright and appear gray, anechoic structures are black as they do not produce any signal, whereas, isoechoic have the same echoes as the surroundings.\textsuperscript{[14]} Several different transducers are available in clinical practice depending on the area being imaged. Commonly used ones are linear probes (bandwidth 3-12 MHz) for small parts, curvilinear or convex probes (1-5 MHz) for obstetrics and abdominal usage and sector or phased-array (3.5-5 MHz) for echocardiography and gynecological uses [Figure 2]. Certain new and more specialized variants are also available now such as the intracavity probes (transesophageal, transrectal, transvaginal), biplane probe, and intravascular probes.\textsuperscript{[11,14]}

\textbf{Different imaging mode displays available in US}

\begin{itemize}
\item A-mode displays the amplitude of the reflected sound. It is used for measuring the boundaries of tissues of different acoustic properties.\textsuperscript{[3]}
\item B-mode produces different echogenicity and shows the texture and tissue borders as black and white images.\textsuperscript{[6]} As US wave passes through tissues of different acoustic impedance, some are reflected back, and some penetrate deeper. The echo signals so received from many coplanar impedance generate an image.\textsuperscript{[14]} Owing to the wide gray scale used, even very small differences in echogenicity can be visualized.
\item Motion mode, it is a two-dimensional image that allows recording the motion. It has a high temporal resolution and is valuable in the accurate evaluation of rapid movements example in the heart.\textsuperscript{[4]}
\item Doppler mode this mode is based on the “Doppler effect” which is defined as “the observed changes in the frequency
of transmitted waves when relative motion exists between the source of the wave and an observer. This enables the examination of blood flow in vessels on the basis of backscatter from erythrocytes.

**Color Doppler**

It depicts vascular flow in terms of the direction of blood flow and its mean velocity in the area of concern. Based on the Doppler shift, it uses color coding to delineate the feeder vessels, namely red color for arteries and blue for veins. The arterial or venous nature is defined with a spectral wave pattern that is plotted with time on the X-axis and Doppler frequency on the Y-axis. It is especially of use in vascular tumors and vascular malformations. Other techniques in use are continuous wave Doppler, pulsed wave Doppler, Doppler duplex, and power Doppler.

**Technical Advances in US Equipment**

Transducer technology and array designs are constantly improving. Developments include portable scanners, high-frequency scanners (above 20 MHz), and miniature pocket-size scanners (8.9 cm display and 3 MHz phased array for color Doppler imaging). Broadband transducers with new piezoelectric materials are available. The Focused US is being used to overcome the rapid decrease in exposure within the sonication path. Focusing overcomes the attenuation loss and concentrates energy deep in the body with little effect on tissues. The US is focused by radiators, lenses, or reflectors.

Current B-mode US includes special imaging modes such as tissue harmonic imaging and spatial compound imaging (multibeam imaging). In modern units, a second harmonic component is also employed, frequency of which is twice that of initiating signal. This results in the reduction of artifacts in the tissues. Spatial compound imaging is the means of electronically routing parallel US beams to image the same area several times. The echoes are then compounded into a single image. This produces reduced “noise” as well as improved contrast and margins.

Enhanced image resolution has been attained through the use of contrast-enhanced US using micro bubbles. It has also increased the sensitivity of US in tumor detection and most of the functions performed currently by computed tomography (CT)/magnetic resonance imaging (MRI) can be allocated to US as well.

Variations of US principle have been implicated in several specifically designed techniques. One among these is, transcranial Doppler that uses a low-frequency (≤2 MHz) sector or curved linear array transducer probe, for dynamic monitoring of intracerebral blood flow velocity and vessel pulsatility. Its varied applications in vascular pathologies include the quantification of right to left shunts, subarachnoid hemorrhage, intra- and extra-cranial arterial stenosis, micro embolism and in raised intracranial pressure.

3D US is another technical advancement that was proposed and patented first in 1987. It involves the transmission of sound waves at different angles and reconstruction of the returning echoes using the complex software to obtain a 3D volume data. Four-dimensional (4D) US is further modified the version of 3D US, in which the fourth dimension of time is added. That is, the images are produced in “real time” thus avoiding the time lag observed with the computer-based reconstructions as is the case with 3D US. 3D/4D US is principally used in obstetrics for fetal anomaly detection, echocardiography for congenital heart defects and neurology to assess the brain development. However, other gynecological and cardiac applications are also receiving the attention of late.

US elastography is a technique for evaluating the elastic properties of soft tissues, quantitatively or qualitatively based on the elastic modulus of tissues. Two types developed are “shear wave based” and “real-time tissue elastography,” which are used for the measurement of liver stiffness. It has found that the application in masticatory muscle assessment in patients with TMDs or submucous fibrosis and to differentiate between the benign and malignant tumors in the thyroid, as well. Real-time tissue elastography that uses a grayscale US machine has also been developed by incorporating elastography into the conventional US scanner. Elastography, although still partly under research, has shown the promising results.

Recent digital communications in medicine specifications have enabled full integration of US with picture archiving and communications system thus, regulating the storage and transfer of images. With the innovative newer technologies set to revolutionize the US practice, it has been ensured that US is encompassed by the mainstream dentistry.

**Applications of US in Maxillofacial Imaging**

Imaging of structures in head and neck can be performed with exquisite details using US.
Swellings of head and neck region US can be used in establishing the differential diagnosis of cystic or solid masses of the neck, cervical lymphadenopathy. It serves to differentiate benign from malignant masses and intra glandular and extra glandular anomalies of the salivary glands.

**Inflammatory swellings**

Siegert et al. (1987) had initially classified the US appearances of inflammatory swellings into five types edema, infiltrate, pre-abscess, echo-poor abscess, and echo-free abscess.\[24,25\]

**Cystic swellings**

Cysts appear as an anechoic area due to its 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 hyperechoic area. For example, branchial cyst and sebaceous cyst classically appear as well defined, homogenous, anechoic, and hyperechoic areas respectively with posterior acoustic enhancement.\[15,26\]

**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 (Figure 3). Hemangioma appears as multiple hypoechoic areas with some amount of vascularity on Doppler study.\[15,26\]

**Malignant neoplasms**

The US 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 such as irregular, poorly defined margins, and heterogeneous internal structure.\[15,26\]

A study conducted by Shankar et al. established the reliability and diagnostic efficiency of US in head and neck swellings.\[26\] The sensitivity and specificity of US 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 were 92.86% and 100% respectively.\[26\] 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.\[15,26,27\]

**Oral submucous fibrosis (OSMF)**

US can be used to demonstrate the number, length and thickness of the fibrotic band.\[28\] OSMF shows the increased hyperechoic areas representing the fibrous bands or diffuse fibrosis.\[3\] Color Doppler and spectral Doppler shows the decreased vascularity and peak systolic velocity in the lesional area.\[28\] Masticatory muscle hypertrophy is also seen in OSMF patients who can be assessed with US. Chakravarty et al. measured the thickness of masseter muscle by ultrasonography (5-11 mHz) and found it to be increased in OSMF as compared to a control group. Also, the thickness was more during contraction as compared to relaxation in both OSMF patients and normal individuals.\[28\] Krithika et al. characterized the US features of the buccal mucosa in the 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 the increased submucosal echogenicity and reduced echo differentiation was present in submucosa and muscle layer in OSMF cases.\[30\]

**Salivary gland ultrasonography (SGUS)**

Various parameters that can be studied using US includes salivary gland volume, the 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 [Figure 4a and b]. SGUS studies can be used to differentiate the inflammatory, cystic or neoplastic swellings of salivary glands.\[25\] Salivary gland obstruction presenting with the 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 (<2 mm) that present sans a shadow. The duct proximal to the stone sometimes shows the visible dilatation, and even radiolucent lith can be visualized using US.\[24,27\] Obstruction in the absence of sialolithiasis can be attributed to the ductal strictures which can be seen in US as hypoechoic ducts with tapering along with an enlarged gland.\[26\]

---

**Figure 3:** Ultrasonographic image of a lipoma in the right cheek overlying the mandible seen as a focal area in the subcutaneous soft tissue plane with echotexture similar to subcutaneous fat.
SGUS also has been used for diagnosing primary Sjogren’s 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 classification criteria for SS increased the sensitivity to 87.0%.\[31\]

**Cervical lymph node assessment**

Pre-operative US imaging plays an important role in delineating the surgical treatment plan in malignancies. Normally, the lymph node appears as a homogeneous hypoechoic area with a thin cortex and shows hilar vascularity or largely avascular areas in color Doppler mode [Figure 5a and b].\[32,33\] Reactive lymph nodes are hypoechoic with or without the presence of echogenic hilus whereas neoplastic nodes have indefinite internal or hilar echoes.\[34\]

In a study by Hwang and Orloff, the sensitivity and specificity of US 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.\[35\] Another study by Kagawa et al. quantitatively evaluated the relationship between vascularity within the lymph nodes and lymph node size on Doppler US images of patients with oral cancer. They conclude that an increase in vascularity was a characteristic Doppler US finding in small metastatic lymph nodes, and as the size increased, blood flow signals got scattered and the scattering index increased.\[36\]

**TMDs**

High-resolution ultrasonography that shows “real-time” images of the articular disc during the mouth opening has been used in the evaluation of TMDs. US image of the disc is of a thin homogenous, hypo/isoechoic band whereas mandibular condyle and the articular eminence are appreciated as hypodense lines.\[34,35\]

In closed mouth position, an 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, the disc is regarded as anteriorly displaced. In open mouth position, normalcy is defined by intermediate zone located between the condyle and the articular eminence.\[34,36\] Razek et al. (2015) assessed the pattern of articular disc displacement in patients with internal derangement using US and concluded that the diagnostic efficacy of US for anterior displacement has sensitivity of 79.3%, specificity of 72.7%.\[37\]

**Other applications of US**

Periapical and intraosseous lesions, maxillofacial trauma, detection of foreign bodies, US guided fine needle biopsy, submandibular gland injection of botulinum toxin for hypersalivation in cerebral palsy and in basket retrieval of salivary stones.\[11\]

US has gained an importance for squamous cell carcinoma (SCC) involving the base of the tongue which is difficult to assess clinically. US based measurement of TT can guide the surgical resection by giving an indication of grade of malignancy.\[38\] A study by Yesuratnam et al. investigated the correlation between TT of SCC of the tongue, obtained by USG and MRI with the histological specimens. They concluded that a high correlation existed thus establishing the utility of US to ascertain pre-operative TT.\[38\] Also, US-based quantitative assessment of tongue shape and movements has been used in phonological research to aid the speech therapy in compromised patients.\[39\]

Color Doppler US has also gained popularity in the 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 such as hemangiomas, lymphangiomas or slow-flow and high-flow vascular malformations.\[17\] A common color Doppler presentation of arteriovenous malformation of the tongue is described as a hypoechoic area with lobulated margins with the depiction of feeder vessels as well.\[17\] The US here serves not only as a diagnostic procedure but provides the treatment guidance as well.

**Merits and Demerits of US**

US is a dynamic technique and useful in the evaluation of soft tissue structures. Most importantly, it is non-invasive, doesn’t
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 US has improved manifold. US is now available in a compact form for clinical use.

The flip side of the coin being, US is still highly operator dependent and hinges a great deal on the experience and knowledge of the operator. Since, specific, reproducible scan planes aren’t available for US, 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.\(^{[11]}\)

The features and utility of US are comparable with that of other modalities such as CT and MRI (Table 1).\(^{[1,11,15,39]}\)

### Conclusion

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

### References
