Ultrasound as a diagnostic boon in Dentistry - A Review

Shubham Sharma,[1]
Deepali Rasila,[2]
Mohit Singh,[3]
Mansha Mohan[4]

[1]BDS, [2]BDS, [3]Post Graduate Student, Department of Prosthdontics and Implantology, D J College of Dental Sciences & Research, Modinagar (Uttar Pradesh) India, [4]Post Graduate Student, Department of Prosthdontics and Implantology, D J College of Dental Sciences & Research, Modinagar, Uttar Pradesh, India

Corresponding Author: Dr. Shubham Sharma, # 1392, Sector 34-C, Chandigarh 160022, Phone: 09888898717, E-mail: docshubhamsharma@gmail.com

Abstract

TMJ imaging protocol begins with hard tissue imaging to evaluate the osseous contours, the positional relationship of the condyle and fossa, and the range of motion.

Many diagnostic means have been indicated for the diagnosis of temporomandibular disorders (TMD), including electrodiagnostic tests such as jaw-tracking devices, electro-myography, thermography, sonography for the evaluation of joint sounds, vibration analysis, and several imaging techniques. Such imaging techniques consist of plain and panoramic radiography, conventional and computerized tomo-graphy (CT) scan, arthrography, magnetic resonance (MRI) and radionuclide imaging.The use of ultrasonography for the diagnosis of tem-poromandibular joint (TMJ) disorders is uncommon.

Keywords: Temporomandibular joint (TMJ), Three Dimensional (3D), Two Dimensional (2D), Ultrasound

INTRODUCTION

After William Roentgen discovered x-rays in 1895, the head & neck region began to be explored in ways that had never been possible before the development of radiology grew at a good place until the World War II. Dental radiology has long played an exerting & critical diagnostic role in dentistry, never truer than now rapidly expanding array of imaging modalities. Recent decades have been the development of Computed Tomography, Magnetic Resonance Imaging, Nuclear Medicine and Ultrasonography. These imaging modalities that have revolutionized dental & medical diagnosis.[1]

All diagnostic ultrasound applications are based on the detection & display of acoustic energy reflected from interfaces within the body.[2]

After the evolution of 2-D ultrasonography systems have been developed that are capable of preserving quantitatively the amplitude information termed gray scale ultrasonography.[3] in the last decade, by combining advances in ultrasound image quality with recent advances in 3D visualization developed the 3D ultrasound which has demonstrated advantages both for diagnosis of disease and in providing image guidance for minimally invasive therapy.[4]

The development of contrast agents for ultrasound has opened new horizons for this non-invasive modality for enhancing the echogenicity of blood and for delineating other structures of the body.[1,5,6]

Its application in dentistry has been used to investigate salivary glands, cysts and tumors in the oral region and in diagnosis of temporomandibular joint disorders, midfacial fractures, fractures of mandibular condyle and ramus, cervical lymphadenopathy and swelling in oro-facial region. Ultrasound guided core needle biopsies recommended as a safe and reliable technique in the diagnosis of cervico-facial masses with a high diagnostic yield.[6]

GENERAL REQUIREMENTS FOR RADIOLOGICAL ULTRASOUND SCANNERS[7-9]

Minimum[9]

- Display examination details
- Electronic adjustment of focal zone
- Movable zoom box

- Simultaneous display of at least two modes
- Cineloop for 5 seconds at 25 frames per second
- Hard disk storage of adequate capacity
- Controllable signal processing facilities
- Tissue specific pre-sets capability
- Caliper accuracy of better than 2% or 0.5 mm
- Screen and hardcopy image distortion of less than 5%
- Tissue harmonic imaging

Desirable[9]

- High definition, variable size display magnification
- Extended field of view
- Digital beam former
- Cineloop up to one minute at 25 frames per second
- Ability to store images digitally (more than 0.5 Gb)
- Fast random access image review
- Removable storage media (DVD, CD or MO)
- Automated tissue specific pre-sets
- Customizable pre-sets and calculations for individual users and for different types of applications for all modes
- DICOM-3 standard
- Microbubble contrast imaging facility[2]

Safety and Quality Assurance (required)[9]

- Compliance with Medical Devices Directive
  All newly delivered equipment should be checked in accordance with MDA DB9801 Supplement 1 Dec 1999: - Checks and Tests for Newly Delivered Medical Devices
- Annual electrical safety tests to be carried out by personnel/contractors trained in safety tests on ultrasound units
- Regular maintenance by qualified personnel for the planned lifetime of the machine
- Full maintenance and service contract with an appropriate organization
- Annual or biannual monitoring of the performance of the unit (QA)by qualified operators

Controls Needed[7]

- An overall sensitivity control to alter the amount of information on the screen.
- Separate controls to alter the surface (near)echoes and the deep (distant)echoes. These are known as near gain and fair gain controls.
- A control (frame freeze)to hold the image on the screen so that it can be viewed for as long as necessary.
- A control to measure the distance between two points and distance between dots should be shown automatically in cm or mm on the screen.

Transmitter – most clinical applications use pulsed ultrasound in which brief bursts of acoustic energy are transmitted into the body. The ultrasound transducer that is the source of these pulses is energized by application of precisely timed, high-amplitude voltage.[2]

Tranducer – A transducer is any device that converts one form of energy to another. In case of ultrasound, the transducer converts electric energy to mechanical energy and vice versa.[2]

Ultrasound transducers use piezoelectricity, a principle discovered by Pierre Curie in 1880. Each transducer is focused at a particular depth.[2]

In pulsed operating modes, ultrasound pulses contain additional frequencies both higher and lower than preferential frequency. The range of frequency produced by a given transducer is termed its bandwidth. Generally, shorter the pulse of ultrasound produced by the transducer, greater the bandwidth.[2]

For continuous wave (CW)ultrasound devices, a constant alternating current is applied to the transducer, the alternating polarity producing a continuous ultrasound wave.[2]

Near field or Fresnel zone – Interference of pressure waves result in an area near the transducer in which the pressure amplitude varies greatly. This region is termed as the Near field or Fresnel zone.[2]

Far field or Frauenhofer zone – from the transducer at a distance is determined by the radius of the transducer and the frequency, the sound field begins to diverge and the pressure amplitude decreases at a steady rate with increasing distance from the transducer. This region is called the Far field or Frauenhofer zone.[2]

The shapes of scans from different transducers are –

1. Linear Arrays –. Used for small parts, vascular and obstetric applications.[7]
2. Curved Arrays – linear arrays that have been shaped into convex curves.[2]
3. Phased Arrays
4. Two-Dimensional Arrays –
   Receiver- The receiver detects and amplifies the weak signals and provides the means of compensating for the differences in echo strength, which result from attenuation by different tissue thickness by control of time depth compensation or time gain compensation (TCG). Another important function of the receiver is the compression of the wide range of amplitudes returning to the transducer into a range that can be displayed to the user.[2]

Image Display- Ultrasound signals may be displayed in several ways –[7, 2]

1. A-Mode
2. M-Mode –
3. B-Mode
4. Real–time

Special Imaging Modes[2]

1. Harmonic imaging
2. Spatial Compounding –
3. 3-D Ultrasound

Image storage – the brightness and contrast of the image on this display are determined by the brightness and contrast settings of the video monitor, by the system gain setting and the TCG adjustments.[2]

Image quality –[2] the key determinants of the quality of an ultrasound image include its spatial, contrast, and temporal resolution, and freedom from certain artifacts.

Spatial resolution[2] – the ability to differentiate two closely situated objects as distinct structures is determined by the spatial resolution of the ultrasound device and must be considered in three planes, and there are different determinants of resolution in each of these.

Axial resolution[2] – the resolution along the axis of the ultrasound beam and is determined by the pulse length. Transducer operating at 5 MHz produces sound with a wavelength of 0.0308 mm.

Lateral resolution[2] – refers to resolution in the plane perpendicular to the beam and parallel to the transducer and is determined by the width of the ultrasound beam. It is controlled by focusing the beam, usually by electronic phasing, to alter the beam width at a selected depth of interest.

Elevation or azimuth resolution[2] – refers to the slice thickness in the plane perpendicular to the beam and to the transducer and is determined by the construction of the transducer and generally, it cannot be controlled by the user.

Ultrasound imaging and Doppler ultrasound are based on the scattering of sound energy by interfaces formed of materials of different properties through interactions governed by acoustic physics.[2] The sound waves used diagnostically in ultrasound have a frequency over 20 000 cycles per second (20 kHz), whereas the audible range for humans is up to 20 kHz.[7]

Sound waves are propagated through a medium by the vibration of molecules (longitudinal waves). Within the wave, regular pressure variations occur with alternating areas of Compression, which correspond to areas of high pressure and high amplitude.

Rarefaction or low pressure zones where widening of particles occurs.

Interaction of Ultrasound with Tissue

This can be described by attenuation, reflection, scattering, refraction and diffraction.

Attenuation is the decrease in amplitude and intensity of wave as it travels through a medium.[8] higher frequencies are more readily absorbed and scattered (attenuated)than lower frequencies.[7]

It is determined by the insonating frequency and the nature of the frequency of the attenuating medium and attenuation of common tissues.

Reflection means the waves are thrown back or return back to the transducer.[2] The way ultrasound is reflected when it strikes an acoustic interface is determined by size and surface of the interface.[2]

Refraction the change in direction of propagation is called refraction. If the sound has been refracted, the echoes detected and displayed in the image may, in fact, be coming from a different depth or location than is shown in the display. Increasing the scan angle so that it is perpendicular to the interface minimizes the artifact.[2]

Diffraction the ultrasound beam spreads out with distance from the transducer. This has the effect of lessening the intensity of the beam.[2]

Mechanism of Scanning[7]

Ultrasound pulses of the type produced by the scanners are of a frequency from 2 to 10 MHz. The duration of the pulse is about 1 microsecond and the pulses are repeated about 1000 times per second.[7]

The reflected ultrasound pulses detected by the transducer need to be amplified in the scanner. The echoes that come deep within the body are more attenuated than those from the more superficial parts, and therefore require more amplification. Ultrasound scanners have control that can alter the overall sensitivity, the "threshold", of the instrument, as well as change the amplification of the echoes from different depths to achieve a balanced image.[7]

Three-dimensional (3-D) Ultrasound

Over the past few years, the development of real-time 3-D ultrasound imaging has revealed a number of potential applications in image-guided neurosurgery as an alternative approach to open magnetic resonance (MR)and intra interventional computed tomography (CT).[10,11]

In a 3D ultrasound examination, the 2D ultrasound images are combined by a computer to form an objective 3D image of the anatomy and pathology (Figures 1-4). This image can then be viewed, manipulated and measured in 3D by the physician on the same or another computer. Also, a 2D cross-sectional image can be generated in any orientation, without restriction, at any anatomical site, which may easily be registered with a previous or subsequent 3D image. Thus, 3D ultrasound imaging promises to overcome the limitations of 2D ultrasound imaging.[4,10-12]

Scanning Techniques

Most 3D ultrasound imaging systems make use of conventional 1D ultrasound transducers to acquire a series of 2D ultrasound images, and differ only in the method used to determine the position and orientation of these 2d images within the 3D image volume being examined.[4]

Advantages

1. 3-D imaging permits volume data to be viewed in multiple imaging planes and allows accurate measurement of lesion volume.[2]
2. It offers both for the diagnosis of disease and in providing image guidance for minimally invasive therapy.[4]
3. The major advantage of 3-D US over existing intra-operative imaging techniques are its comparatively low cost and simplicity of use.[10]
4. Its ability to measure the length, area or volume of organs or lesions in arbitrary orientations.[4]

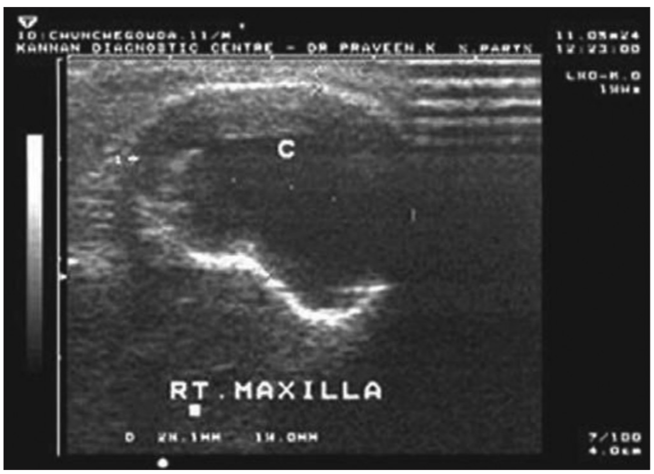

Figure 1: Ultrasonographic picture of the swelling showing oval-shaped lesion with anechoic internal echo pattern and unchanged posterior wall echo. These features are suggestive of a dentigerous cyst

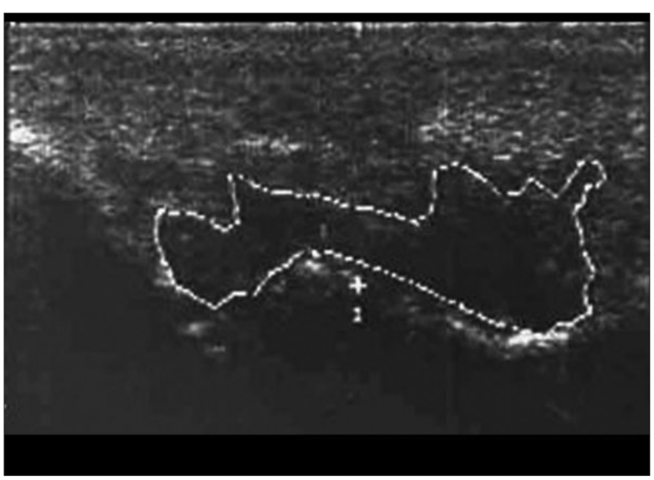

Figure2 : Ultrasonography picture showing anechoic lesion in the region of buccal space suggesting of buccal space abscess. (USG, 8 MH2 probe)

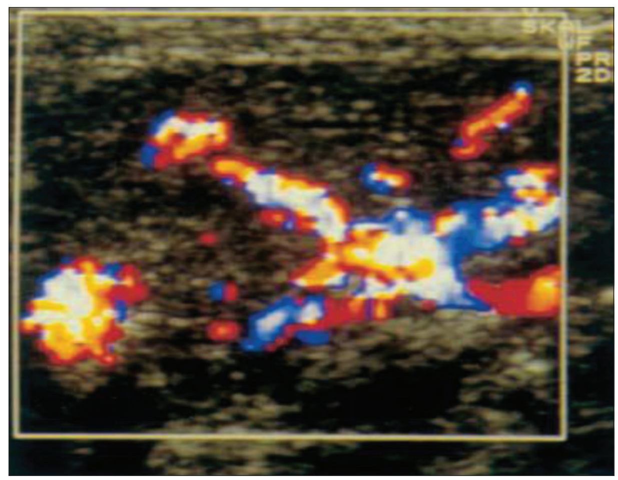

Figure 3: Longitudinal sonogram of the parotid gland. Unilateral hypoechogenic swelling of the gland, color Doppler reveals hyperemia. Acute sialoadenitis was diagnosed

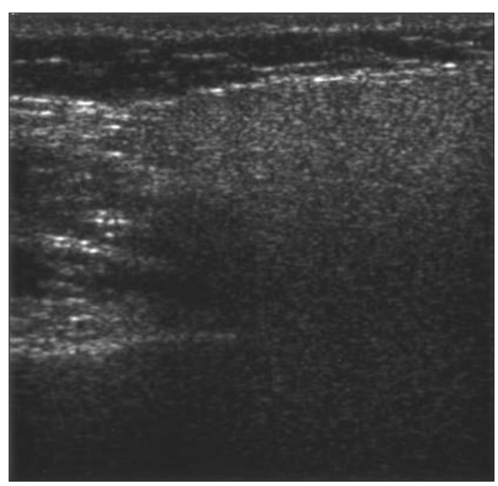

Figure 4: Transverse sonogram of the left parotid gland. Echogenic swelling of both parotid glands was present. The deep parts of the gland are not visualized due to strong acoustic attenuation. Sialoadenosis was diagnosed

Measurement Accuracy with 3D Ultrasound

1. Distance measurement - With a 3D image, distance measurements need not be made in the plane of an acquired 2D image, but instead can be made in any orientation.[4]
2. Measurement of cross-sectional area using 3D ultrasound- Using the multiplanar reformatting (MPR)technique, the 3D image can be 'sliced' in any orientation, to obtain the optimal cross section for the organ measurement.[4]
3. Volume measurement using 3D ultrasound- The availability of 3D images allows the measurement of organ volume using either manual or algorithmic techniques.[4]

Doppler Ultrasound

Doppler ultrasound is based upon the Doppler Effect. Christian Andreas Doppler (Austrian mathematician and physicist)1841 proposed that the observed color of a star was caused by a spectral shift of white light that occurred because of the motion of the star relative to the earth. Doppler used analogies based on the transmission of light and sound. Although his theory on light was in error, Doppler's theories on the change in frequency of sound waves were correct.[6]

The Doppler Effect – the Doppler Effect, as the theory became known, is defined as "the observed changes in frequency of transmitted waves when relative motion exists between the source of the wave and an observer". This theory was applied to many aspects of science, including astronomy and medicine.[6]

ADVANTAGES

1. It is a dynamic and readily available technique.[13]
2. It is particularly useful in the examination of superficial structures.[13]
3. It is widely available and relatively inexpensive.[12]
4. It is a non-invasive technique.[12]
5. It is well tolerated by the patient.[13]
6. It does not interfere with normal function.[14]
7. Artifacts are few.[13]
8. The technique is highly acceptable to most patients.[13]
9. Images are rapidly acquired.[13]
10. Images are simple to store and retrieve.[15]
11. Images obtained are easy to read once the observer is trained.[16]
12. It can be performed without heavy sedation.[12]
13. It has no known cumulative biological effects.[18]
14. It is proven to be reproducible and simple.[17]
15. Equipments are portable.[19]
16. It is easily accessible and painless.[20]
17. It is a less discomfort, relatively rapid and examination can be performed even at the patient's bedside.[20]
18. Its absolute non ionizing nature.[20]
19. Equipments are relatively cheap.[16]
20. It is convenient to use.[16]
21. Its possibility of real time imaging.[21]
22. It helps to distinguish between solid and cystic lesions.[20]
23. Its ability to detect non calcified pathological entities such as sialoliliths.[21]

DISADVANTAGES

1. The technique is very operator- and equipment dependent.[12]
2. Clinically only the bone surfaces and not the whole cortex or spongiosa can be visualized in intact done due to ultrasound frequencies.[22]
3. It has to be performed by experienced investigators.[19]
4. Images when archived they may be difficult to orientate and to interpret unlike CT and MR scans, which have acquired in standard reproducible scans.[13]
5. The difficulty of picturing the TMJ using ultrasounds depends on the limited accessibility of the deep structures, especially the disc, due to absorption of the sound waves by the lateral portion of the head of the condyle and the zygomatic process of the temporal bone.[23]
6. Ultrasound images are affected by inherent noise accompanying the signal returned to the transducer which makes interperatation of the static images, and sometimes the dynamic ones as well and a nonmoving object will vary in appearance because of this noise.[15]
7. Ultrasonography waves do not visualize bone or pass through air, which acts as an absolute barrier during both emission and reflection.[23]

Depending on the application and ultrasonic intensities it is divided into two-

Diagnostic ultrasound – the ultrasonic intensities used are typically 5 to 500 mW/cm^2 and it includes:

- Swellings in orofacial region
- Salivary glands disorders
- Periapical lesions
- Lymph nodes – benign/malignant
- Intraosseous lesions
- Temporomandibular disorders
- Assessment of masticatory muscles in temporomandibular dysfunction
- Congenital vascular lesions of head and neck
- Primary lesions of the tongue

- Fractures of mandibular condyle and ramus and midfacial fracture
- Detecting the foreign bodies
- Distracted mandibular bone
- Miscellaneous lumps and bumps of the head and neck
- Ultrasound guided
    - Core needle biopsy
    - Submandibular gland injection of botulinum toxin for hypersalivation in cerebral palsy
    - Basket retrieval of salivary stones

2. Therapeutic ultrasound – use intensities of 1 to 3 W/cm^2 and it includes –

- Myofascial pain
- Temporomandibular joint dysfunction
- Ultrasound guided lithotripsy of salivary calculi using an electromagnetic lithotripter
- Bone healing and oestointegration
- Oral Cancer
- Healing of full thickness excised skin lesion.
- Other applications-
    - Ultrasonic descaling
    - Modifications of the ultrasonic descaling
        1. Endodontics
        2. Surgical applications
        3. Other dental uses
        4. Ultrasonic cleaning baths

SUMMARY & CONCLUSION

Radiography has been widely used for obtaining a comprehensive overview of the maxillofacial complex. The clinical use of Radiography is limited by the uncertainty regarding the actual dimensions of structures.[24] Ultrasonography has revolutionized the world of medical imaging as a diagnostic and therapeutic aid. Though diagnostic ultrasound has been used as a reliable diagnostic tool in the medical field but still not found its place as a routine diagnostic aid in the orofacial region.

It is recognised as one of the most risk-free methods of evaluating any disease in the human. Ultrasound real time imaging has wide application in numerous diagnostic fields.

It has been suggested that it can provide useful information for the assessment of TMJ disorders. Despite the limitations that it is operator dependent, better standardization is required and normal parameters must be set and it remains potentially useful as an alternative imaging technique for monitoring TMJ disorders particularly for the diagnosis of articular disc displacement and joint effusion. It may be acceptable treatment of choice in many types of clinical procedures involving maxillofacial bone.

It has several advantages over conventional radiography namely its non- invasive nature, easy reproducibility, possibility of real time imaging, its ability to detect non calcified pathological entities, relatively rapid and inexpensive technique.

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