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Review Article

Echoes in Endodontics: a Comprehensive Review of Applications of Ultrasonography in Endodontics

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ABSTRACT

Ultrasound (US) imaging is a minimally invasive, radiation-free imaging modality that is known for its versatility in Medical diagnostics. Recently, it has emerged as a promising tool in the field of Dentistry as well, finding varied applications such as in the detection of carious lesions, tooth fractures, soft tissue lesions, periodontal bony defects, maxillofacial fractures, salivary gland disorders, and temporomandibular disorders. This comprehensive review discusses the applications of US imaging in Endodontics.

Keywords: bone healing, diagnosis, periapical lesions, pulp vitality, ultrasonography

Introduction

Dental imaging holds the utmost significance when it comes to the diagnosis and treatment planning of lesions pertaining to the oral and maxillofacial structures. Periapical radiographs have been the backbone of endodontic diagnosis since time immemorial; however it carries the risk of exposing the patients to harmful ionizing radiation. Recent decades have seen a revolutionary advent in the field of Dental radiology in the form of Computed Tomography (CT), Magnetic Resonance Imaging, Cone Beam Computed Tomography (CBCT), and also Ultrasonography (USG), which have opened new vistas in the field of Diagnostic Endodontics.[1] This review article is thus aimed to provide an insight into the applications of Ultrasonography in the field of Endodontics in particular.

The technical basis of Ultrasonography

Ultrasound (US) is defined by the American National Standards Institute as “sound at frequencies greater than 20 kHz.” [2] Ultrasonography (USG), also known as real-time echography or sonography, is an imaging technique where a beam of ultrasound propagates through the internal tissues and is reflected, absorbed or transmitted to form an image. An ultrasound scanner consists of several components including a transducer probe, a monitor, a central processing unit (CPU),

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a keyboard with control knobs, a printer, and disk storage devices. However, the most essential of them all is the transducer probe.

Transducer probe – A transducer is any device that converts one form of energy to another. In the case of ultrasound, the transducer is used to convert the electric energy to mechanical energy and vice versa. This probe both produces the sound waves used in ultrasound and receives their echoes back. It works on the “piezoelectric” phenomenon. This phenomenon was first discovered by Pierre and Jacques Curie. This effect causes quartz crystals contained in the ultrasound probe to vibrate rapidly and send out mechanical sound waves when an electrical current is applied to them. This same effect also causes the crystals to give off electrical currents when the reflected sound waves from an ultrasound examination; echo back to them. This is how quartz crystals in an ultrasound probe can both send and receive ultrasound waves.[3]

Different transducers are available which are used for different parts of the body and have a shape unique to them:-[4]

a) Linear Arrays: has a wide footprint and a central frequency of 7.5Mhz – 11Mhz. It is used for small parts, vascular and obstetric applications.[5]

b) Curved Arrays: linear arrays that have been shaped into a convex curve have a wide footprint and their central frequency is 2.5MHz – 7.5MHz. it is used for abdominal examinations. A variant of it is a micro convex probe which is used for neonatal examinations.[3]

c) Phased Arrays: has a small footprint and low frequency of 2 Mhz – 7.5 Mhz. The beam shape is almost triangular and used mainly for cardiac and abdominal examinations.

d) Pencil transducers: also called CW Doppler probes are employed to measure blood flow. This probe has a small footprint and uses a low frequency of typically 2 Mhz– 8 Mhz.

e) Endo-cavitary ultrasound transducer type: These probes are used to perform internal examinations of the patient. These probes allow a wider field of visualization than providing a depth of range.

Generally, ultrasound with frequencies between 3 MHz and 12 MHz is used in dentistry.[6] The most commonly used dental display modes are amplitude mode (A-mode) and brightness mode (B-mode). A-mode ultrasound is the most basic display mode after plotting the radiofrequency (RF) signal and was used often in the early US. It uses a single crystal to generate a one-dimensional image with the echo amplitude, which is shown as peaks, thus enabling the measurement of the distance between various structures. Currently, a standard screen image created by US machines is in B-mode. B-mode ultrasound images are produced when an ultrasound probe is moved on a trajectory, thus displaying images of all the tissues, traversed by the probe. The images are inherently two-dimensional, but when multiple B-mode images are viewed in a rapid sequence, a real-time image is produced.[7,8]

The sonogram is a composite image of variable shades of gray. the brightness of which depends on the echogenicity is the ability of a tissue to reflect or absorb sounds, and this frequency of the reflected echoes determines the brightness of the Ultrasound image. With the diagnostic US, tissues are classified based on their echogenicity in broad categories: [9]

- Hyperechoic or echogenic, highly reflective tissues (very bright), such as osseous structures or cartilage
- Moderately echogenic (fairly bright), such as glands

- Hypoechoic (fairly dark), such as blood vessels and muscles
- Anechoic (very dark), such as fluids and air.

The US has been coupled with Color Doppler to visualize the direction and velocity of blood flow within a defined region of interest. In a process similar to pulsed-wave Doppler (PWD), color flow Doppler utilizes intermittent sampling of ultrasound waves thereby avoiding the range ambiguity characteristic of continuous-wave Doppler (CWD). The distribution and the direction of the flowing blood are imaged two-dimensionally in which the velocities are illustrated by different colors. The flow that travels away from the transducer (negative Doppler shift) is depicted in blue, and the flow that is traveling toward the transducer (positive Doppler shift) is depicted in red. A lighter shade of each color is indicative of higher velocities. A third color, usually green or yellow, indicates areas of high flow turbulence.[10]

The first data of diagnostic US in dentistry were published in 1963 by Baum *et al.*[11] who tried to visualize the internal structures of teeth with a transducer. Many other applications of US in dentistry have been explored since, such as caries detection, imaging of dental and maxillofacial fractures, visualization of cracks, soft tissue lesions, periodontal defects, temporomandibular and implant disorders, and the measurement of muscle and gingival thickness.[7,12]

Applications in Endodontics

1. Diagnosis of Periapical Lesions

Periapical lesions accompanying endodontic infection are usually diagnosed and treated based on the preliminary radiological findings which encompassed Intra Oral Periapical Radiography traditionally. Sometimes a periapical surgery is necessary to eliminate and to diagnose the cystic and non-cystic nature of the lesion. It thus becomes an important task to diagnose a periapical lesion as a cyst or a granuloma and also if it is a true cyst (radiolucent cavities enclosed completely with an epithelial lining) or a false/bay/pocket cyst (when an epithelial lined cavity is open to and continuous with the root canal). Apical true cysts were suggested to be less likely to heal by nonsurgical root canal therapy because they are self-sustaining and no longer dependent on the presence or absence of root canal infection, based on post-treatment histopathologic diagnosis of one surgical biopsy report.[13] Accordingly, surgical intervention of apical true cysts is required. A histopathological examination is of paramount importance while obtaining a confirmatory diagnosis of the periapical lesion because it governs the line of treatment. However, it is impractical in a non-surgical treatment case. The low accuracy rate of Conventional Radiography (26%[14] -54.3%[15])·and Cone Beam Computed Tomography(61%-76%)[16,17] have urged a necessity to search for a minimally invasive imaging modality that can diagnose periapical lesions with good accuracy.

Cotti *et al.* reported the differential diagnosis of periapical granulomas and cystic lesions using USG, which were confirmed by histopathology examinations in all 11 cases.[18] The ultrasonographic picture of periapical lesions reported by the study is as follows:

i. Cystic lesion: A hypoechoic well-contoured cavity surrounded by thickened bone walls and filled with fluid, and with no evidence of internal vascularization on the Color Doppler examination.

ii. Granuloma: A poorly defined hypoechoic area, showing rich vascular supply on Color Doppler examination.

iii. Mixed lesion: Predominantly

hypoechoic area with the focal anechoic area, showing vascularity in some areas on the Color Doppler examination.

The accuracy rates of different authors when USG was compared to other radiographic imaging techniques in the diagnosis of periapical lesions ranged from 86 % to 100 % **[Table1]**

2. Assessment of Pulp Vitality

The assessment of pulp vitality and evaluation of the necessity for root canal treatment is among the most important procedures in treating traumatized teeth.[29] False-negative results may lead to unnecessary root canal treatment, whereas false-positive results implications on diagnosis leading to complications such as root resorption, abscess, and sometimes even loss of a tooth.[30,31]

Traditionally, thermal tests and electric pulp testing (EPT) were used to assess pulp sensitivity. However, these are indirect testing methods that rely on subjective sensitivity. However, in immature teeth, teeth with chronically inflamed pulp, teeth that have undergone a recent trauma, or teeth in patients who have lost its sensory function after orthognathic surgery because the apical area witnesses a temporary loss of sensory response owing to inflammation, pressure, or tension of the nerve fibers; accurate status of the pulp is indeterminable. Hence, the direct measurement of blood flow is more preferable.[32,33]

Laser Doppler Flowmetry (LDF) and pulse oximetry are devices that can be used to evaluate blood flow directly, but these also have their own set of limitations. Of late, Ultrasound Doppler Flowmetry (UDF) has also emerged as a promising tool in this arena. It is based on the principle of assessing blood flow by transmitting ultrasound through the tissues. Recently, UDF was shown to be an effective tool in measuring pulpal blood flow velocity utilizing a microfluidic-based pulpal arteriole blood flow phantom.[34] When comparing blood flow velocity in normal teeth with that of root canal–treated teeth, faster blood flow velocity, and the pulsed waveform was observed in normal teeth as opposed to slower blood velocity and no pulsed waveform exhibited by root canal–filled teeth.[35] Recently, a study by Ahn SY *et*

Table 1: Accuracy rates of USG in diagnosing periapical lesions by different authors

Sl No.	Author	Accuracy Rate in diagnosing periapical lesions
1.	Gundappa *et al.*(2006)[19]	100%
2.	Raghav *et al.* (2010)[20]	95.2 %
3.	Goel S *et al.* (2011) [21]	96.6%
4.	Pallagatti S *et al.* (2012) [22]	92.3%
5.	Prince CN *et al.* (2012) [23]	86.7%
6.	Parvathy V *et al.* (2014) [24]	100%
7.	Saeed SS *et al.* (2014) [25]	96%
8.	Nunsavathu PN *et al.* (2015) [26]	90%
9.	Khambete N & Kumar R (2016) [27]	100 %
10.	Zope SR *et al.* (2018) [28]	90%

al.[31] compared the capacity of EPT and UDF to determine pulp vitality in traumatized teeth, and they reported a higher sensitivity for UDF than EPT in assessing pulp vitality in traumatized teeth.

3. Detection of Early carious Lesions

Dental caries is a localized and progressive bacterial infection that disintegrates a tooth, usually beginning with the dissolution of enamel and followed by bacterial invasion.[36.] The disease process which initially begins with numerous episodes of re-mineralization and demineralization finally results in mineral loss and cavitation if the equilibrium shifts to the latter. However, non-cavitated lesions show increased porosity due to sub-surface demineralization. The scattering of reflected light makes the incipient lesion appear opaque, referred to as a white spot lesion(WSL).[37] Although clinicians are mainly dependent on periapical radiographs and bitewing radiographs for detection of occlusal and proximal caries, the above-mentioned techniques are incapable of detecting early and incipient carious lesions. Lately, supplementary state-of-the-art techniques have been discovered to aid in the early detection of carious lesions. These include Laser fluorescence, digital fiber optic transillumination (DIFOTI), quantitative light-induced fluorescence (QLF), electronic caries monitor (ECM), and Optical Coherence Tomography(OCT) and near-infrared transillumination. However, these tools do not present the shape and depth of WSLs that are needed to select the proper treatment options.[38] However, Ultrasonic waves, unlike light waves have greater penetration depth and holds potential in detecting early caries. Kim *et al.*[38.] investigated the ability of high-frequency ultrasound (HFUS) imaging at 40 MHz to detect early dental caries. The results obtained with HFUS comparing it with the conventional US imaging device operating at a frequency of 13.3 MHz. They concluded that the high-frequency B-mode image acquired by the HFUS imaging system showed better spatial resolution and contrast than that of its conventional counterpart in detecting the extent of dental caries lesions, and the images acquired were comparable to micro-CT images concerning the depth measurement.

4. Tracing of sinus tracts

The sinus tract (ST) of endodontic origin is a pathway from an enclosed area of infection (e.g. a root canal) to an epithelial surface through an opening (or stoma), which can be intraoral or extra-oral and represents an orifice through which pressure is discharged; usually disappears spontaneously with the elimination of the causative factor by endodontic treatment.[36] The detection of a tooth with a sinus tract (ST) of endodontic origin and its pathway are traditionally adjudged with a periapical radiograph and a gutta-percha cone or a fine stainless-steel orthodontic wire introduced into its stoma. The identification of the tooth responsible for the ST can be complicated by its opening at a distant site or by the presence of multiple stomas, and when STs open in the skin of the face and neck, they can be easily misdiagnosed as dermatologic diseases.[39] Also, the persistence of STs has been accredited to the presence of extra-radicular infections such as actinomycosis[. 40]

Cotti E *et al* (2019) evaluated the possibility to detect sinus tracts (STs) and trace their route by determining the exact irregularities and curvatures using ultrasound real-time examination. The study also entailed the use of Color Doppler to evaluate the vascularity of the STs. They concluded that US real-time examination can be successfully used to detect the STs of endodontic origin and to trace their route of drainage from the periapical lesion to the opening within the oral mucosa or the skin.[41]

5. Evaluation of post-surgical periapical bone healing

Conventionally, periapical radiographs have been instrumental in evaluating post-surgical periapical healing. In later decades, advanced radiographic techniques evolved such as CT and CBCT. But, all of these modalities lack accuracy due to non-standardization and also carry a risk of unwanted radiation exposure. Recently, US imaging has been employed for assessing bone healing following surgical endodontics.

Maity I *et al* evaluated the reliability of US Imaging for monitoring post-surgical healing on ten patients at intervals of six weeks, three months, and nine months. They found detectable vascularity at the end of six weeks for eight patients, which were indicative of neovascularization, implying progressive healing. Recurrent follow-ups revealed a further decrease in the size, with less detectable vascularity, which were due to the remodeling of the overlying cortical plate; which is thought to hinder the transmission of ultrasonic waves, all of which denoted ameliorated healing of the periapical lesion.[42] A more recent study by Curvers F *et al*[43] also supported the ability of US imaging to assess the initial stages of bone healing with good detection.

Conclusion

Ultrasound imaging has proved its feat in medical imaging for a long time. Its advent in the field of Dentistry has also been evidenced to be promising. In the field of Endodontics, numerous studies have been carried out to prove the same. However, Ultrasound imaging has its own sets of limitations such as its inability to detect changes in tissue underlying thicker cortical plates, and also it has low resolution. Furthermore, no specially designed transducer probes are available by which intraoral examinations could be carried out. Despite these limitations, it can be concluded that USG holds the potential to be used as an adjunct in diagnosis and assessment of bone healing, in addition to its varied use in the field of Dentistry, especially in Endodontics. Further studies are however required to investigate its hidden capabilities, thus fortifying a step towards radiation-free imaging in Dentistry.

Conflict of Interest: None

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Abbreviation

CBCT—Cone beamed computed tomography
CPU—Central processing unit
CT—Computed tomography
CWD—Continuous-wave Doppler
DIFOTI—Digital fiber optic transillumination
ECM—Electronic caries monitor
EPT—Electric pulp testing
HFUS—High frequency ultrasound
LDF—Laser doppler flowmetry
OCT—Optical coherence tomography
PWD—Pulsed wave doppler
QLF—Quantitative light-induced fluorescence
RF—Radiofrequency
ST—Sinus tract
UDF—Ultrasound doppler flowmetry
US—Ultrasound
USG—Ultrasonography
WSL—White spot lesion