TECHNICAL REPORT

Visibility of dental pulp spaces in dental ultrasound

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The purpose of this study was to assess the feasibility of dental ultrasound with conventional sonographic equipment. The teeth of three adult volunteers who had cone beam CT examinations performed previously with clinical indications and one extracted tooth were examined using linear and compact (hockey stick) sonographic probes. The sonographic images were compared with cone beam CT images reconstructed accordingly. Dental pulp spaces were demonstrated in all teeth not covered with prosthetic crowns. The dentin and pulp were best visualized at the level of the neck of the teeth. The dentin was hypoechoic, and the superficial layer comprising the cementum and the pulp spaces were hyperechoic. Dental ultrasound is feasible with general purpose sonographic machines. The buccal surfaces of all teeth are accessible with a compact (hockey stick) probe. Visualization and differentiation of dental pulp spaces, dentin and the superficial layer comprising cementum is possible in the portions of teeth not covered by the alveolar bone or prosthetic crowns. The dental pulp spaces are best seen at the level of the tooth neck. Pulp and endodontic fillings can be distinguished on ultrasound.

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Introduction

Ultrasound has been used extensively in medical imaging for several decades. Its use has been limited mostly to the soft tissues and the surface of bones, since no useful signal can be obtained past the soft tissue–bone and soft tissue–air interfaces.

The first report on sonographic visualization of internal structures of the teeth was published by Baum et al¹ in 1963. However, after the initial papers by Kossoff and Sharpe² and Lees and Barber,^{3,4} this thread of investigation seems to have been abandoned.⁵ Currently, in clinical and investigative dentistry, ultrasound is used for the detection of approximal caries, assessment of the periodontal space, surface imaging of periodontal bony defects and measurement of enamel thickness, and in the differentiation of periapical lesions,

determination of gingival thickness and monitoring of periapical healing after endodontic surgery.^{5–13}

Recently, extensive overviews of applications of ultrasound in dentistry were published by Ghorayeb et al⁵ and Marotti et al.¹³

The purpose of this paper was to investigate the feasibility of dental ultrasound with conventional ultrasonic equipment and to assess the possibility of demonstration of dental tissue on ultrasound.

Materials and methods

This study was approved by the Bioethical Board of the Medical University of Warsaw, Poland (AKBE/65/13).

Study in vivo

Teeth of three volunteers, two males and one female, aged 53, 26 and 58 years, respectively, were examined. All volunteers had cone beam CT examinations performed

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a

b

c

Figure 1 Transverse images of the lower central incisors—sonography (a), explanatory drawing (b) and cone beam CT (c). The dentin is hypoechoic, the hyperechoic pulp spaces are clearly seen

a

b

c

Figure 2 Transverse images of the lower second premolar and first molar—sonography (a), explanatory drawing (b) and cone beam CT (c). Note the hourglass shape of the pulp space of the first molar (arrows)

Figure 3 Longitudinal images of the central upper incisor—sonography (a), explanatory drawing (b) and cone beam CT (c). Note the reverberation artefacts obscuring the internal structure of the crown

using a Planmeca ProMax[®] Mid scanner (Planmeca Oy, Helsinki, Finland). Sonographic images were obtained using Toshiba Aplio[™] (Toshiba Medical Systems, Tokyo, Japan) and Philips HD15 ultrasound machines (Koninklijke Philips BV, Eindhoven, Netherlands). Linear probes were used with the Toshiba Aplio machine (7–14 MHz and 7.2–18.0 MHz), and a compact L15-7io “hockey stick” probe (7–15 MHz) was used with the Philips HD15 machine. The probes were covered with sterile latex sheaths. Dental gel (Elmex gel; GABA International, Basel, Switzerland) was used as a coupling agent. Longitudinal and transverse images were obtained.

Study in vitro

An extracted second lower molar was examined using the Philips HD15 ultrasound machine (with a compact L15-7io “hockey stick” probe). The tooth was extracted 1 week before the sonographic examination and was stored in a mixture of saline and antiseptic agent. During the examination, the tooth was immersed in saline and imaged without the coupling agent.

The images of the teeth obtained using both techniques were compared by two observers (a radiologist with 20 years’ experience in head and neck radiology and a dental surgeon with 2 years’ experience in dentomaxillofacial radiology).

Results

Only the buccal surface of the anterior (incisor and canine) teeth were accessible using the regular linear probes. The buccal and labial surfaces of all teeth were accessible with the compact (“hockey stick”) probe.

The pulp chambers and/or root canals could be demonstrated in all examined teeth not covered with prosthetic crowns. Three areas were visible in the transverse sections at the level of the neck of the teeth: a thin external hyperechoic rim corresponding to the cementum, a hypoechoic area corresponding to the dentin and an inner hyperechoic area corresponding to the pulp spaces (Figure 1). The number, position and relative size of the demonstrated pulp spaces corresponded with the cone beam CT images (Figure 2). The dental pulp spaces were best visualized at the level of the neck of the tooth covered by the soft tissue of the gum. In the crown, the reverberation artefacts originating from the enamel were present. No internal structures of the teeth could be visualized past the level of the alveolar bone (Figure 3).

Similarly, only high superficial ultrasound reflections were visible in teeth with prosthetic crowns, with no internal structure of the teeth identifiable (Figure 4).

The surfaces of the endodontic fillings were hyperechoic with posterior shadowing (Figure 5).

In the extracted tooth, a hyperechoic rim corresponding to the remnants of the periodontal ligament and cementum, hypoechoic dentin and hyperechoic root channels could be demonstrated (Figure 6).

a **b** **c**

Figure 4 Transverse images of the lower premolars—sonography (a), explanatory drawing (b) and cone beam CT (c). The second premolar is covered with a prosthetic crown

a **b** **c**

Figure 5 Transverse images of the lower incisors filled with endodontic material (open arrows)—sonography (a), explanatory drawing (b) and cone beam CT (c). Ultrasound-reflecting surface of the endodontic fillings and posterior shadowing is visible

Figure 6 Transverse image of the roots of a lower second molar—sonography (a) and an explanatory drawing (b). An image *in vitro*, the tooth is immersed in saline. Between the roots, artefacts from the remnants of soft tissue and small bubbles of air are visible

Discussion

Three layers, corresponding to the cementum, dentin and dental pulp spaces, could be demonstrated in the examined teeth. The possibility of sonographic visualization of the internal structures of the teeth and the level of the tooth neck is only apparently surprising. If we assume that the acoustic impedances (Z) of the gingiva, dentin, cementum and pulp are 1.63×10^6 , 6.5×10^6 , 7.6×10^6 and $1.57 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$, respectively, then the intensity transmission coefficients of the sonographic wave are calculated as:

$$G = 1 - \left(\frac{z_2 - z_1}{z_2 + z_1} \right)^2$$

and the gingival/cementum, cementum/dentin and dentin/pulp interfaces can be estimated as 64.1%, 99.4% and 56.8%, respectively.

The imaging of the enamel-coated portions of the teeth is less clear. The images are deteriorated by high echoes and reverberation artefacts. The transmission coefficients of the gingiva/enamel and enamel/dentine can be estimated as 29.4% and 82.0%, respectively, if we assume that the acoustic impedance of the enamel amounts to $18.8 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$.^{5,14}

The thin hyperechoic layer visible on the surface of the imaged portions of the teeth may represent the alveolar–cemental interface, the coupling gel–cementum interface, the cementum itself, the cementum–dentin interface and a combination of or all the above-mentioned structures. The differentiation of the above-mentioned thin structures is not possible with the clinical equipment we used. The dentin was hypoechoic on ultrasound, resembling rather the sonographic image of the cartilage than the image of the bone. The pulp was hyperechoic, reflecting, probably, its complex vascular and fibroblastic structure.

The shape, relative size and number of hyperechoic regions seen in the examined teeth corresponded to the dental pulp spaces demonstrated on cone beam CT. Reverberation artefacts alone would have had the shape of the teeth surface, which is not the case in the examined teeth. This, however, does not exclude the possibility of overlap of the echoes arising in the pulp and some reverberations.

This study had several limitations. The shape of the stiff probe head does not conform to the shape of the teeth surface or the shape of the dental arch; consequently, large amounts of coupling agent are necessary, and only a few teeth can be visualized in a satisfactory manner. This problem could be solved by a custom-designed dental probe.

The sonographic window allowing the best visualization of the pulp spaces is limited to the portion of the tooth neck between the cemento–enamel junction, and the crestal bone narrows possible clinical applications of this technique. However, the use of dedicated dental probes with a fan-shaped field of view could enhance the accessibility of the internal structures of the teeth.

The relatively low frequency of the probes (less than 20 MHz) surely affected the spatial resolution of the sonographic images. Visualization of the pulp spaces was difficult in the longitudinal plane, probably owing to the partial volume effect caused by the thickness of the sonographic beam.

Finally, the difference of speed of the ultrasound in the soft tissue of the gingival (1540 m s^{-1}) and in the dentin (3800 m s^{-1}) might have resulted in the spatial distortion of the images.⁵

In conclusion, the dental ultrasound is feasible with general purpose sonographic machines. The buccal surfaces of all teeth are accessible with a compact (hockey stick) probe. Visualization of dentin, cementum and dental pulp spaces is possible in the portions of teeth not covered by the alveolar bone or prosthetic crowns. The dental pulp spaces are best seen at the level of the tooth neck. Pulp and endodontic filling can be distinguished on ultrasound.

Further studies are warranted to assess possible clinical applications of dental ultrasound—one possible

application could be the assessment of the number of root canals.

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