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Ultrasound Imaging of Dental Implants

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Abstract— **Accurate measurement of soft tissue thickness is needed prior to dental implant placement and prior to surgical uncovering of the implant. Ultrasonography has many potential advantages for use in dental implant surgery, but has not yet been made suitable for clinical use. A 2D ultrasound imaging system and a mechanical positioning system were used to scan dental implants embedded in a porcine jaw, covered by soft tissue, submerged in a water tank. Results indicated that ultrasound can be used to accurately detect, locate, and measure dental implant fixtures and measure the thickness of the overlying soft tissue in an *ex vivo* environment.**

I. Introduction

Dental implants are now the preferred method of replacing lost or missing teeth and a very rapidly growing treatment modality. During dental implant treatment, a threaded titanium implant fixture is placed within the jawbone, beneath the soft gingival tissues (Fig 1). Usually, a soft tissue flap is surgically raised to directly expose the jawbone during placement, and is repositioned after placement. Alternatively, an implant can be placed, using minimally invasive flapless surgery, through a hole carefully punched in the soft tissue. Either way, soft tissue thickness over potential implant sites in the jawbones must be accurately measured. The architecture of the bony alveolar ridge, hidden beneath the soft tissue, must be understood. Key anatomic landmarks such as the mental foramen, through which the delicate nerve to the lower lip exits, must be identified before flap design, soft tissue surgery, and implant placement.

After a period of healing to accommodate the process of osseointegration, prosthetic teeth are usually attached to the implant fixture. When the patient returns for prosthesis fabrication and placement, the buried implant must be precisely located, uncovered, a transgingival abutment of appropriate height and shape placed, and a prosthesis attached.

The ability to accurately measure soft tissue thickness and to locate and characterize anatomic landmarks will facilitate the selection of the implant site, appropriate surgical procedures prior to implant placement, as well as suitable types of implant abutment, restorations and prostheses. This will reduce surgical complications, and facilitate the design of appropriate esthetic and hygienic contours of the restoration.

Current techniques to measure soft tissue thickness and to locate the implant post involve physical penetration of the soft tissues with periodontal probes or radiography. Conventional dental X-rays necessitate interruption of implant surgery and use of cone beam computer tomography (CBCT) is not practical during surgery. Ultrasonography is a potentially useful alternative or addition. Ultrasonography is well suited to identifying physical discontinuities common to dental implant therapy, such as bone-gingiva or titanium-gingiva interfaces. It has high resolution, is noninvasive, can be used intra-operatively in real-time, and lacks the hazards of ionizing radiation.

Ultrasonography has been widely used in medicine for many years, but does not yet have general application in dentistry. Ultrasonography was first applied to periodontal assessment and to measurement of tissue thickness in 1971 [1-2]. Ultrasonographic tissue depth measurement procedures are now more accurate and reliable than direct gingival probing for periodontal measurements around teeth; conventional transgingival probing has typically resulted in overestimations of gingival tissue thickness over bone around teeth [2-7]. Ultrasonographic measurement of bone morphology has been more difficult, but images of gingiva, bone, and periodontal ligaments have been obtained [8-10]. Images of large lesions of endodontic origin, which have penetrated the cortical bone, have also been made [11-13]. However, ultrasound has not yet been applied to implant diagnosis, treatment planning, or to the subsequent implant surgical and prosthetic procedures. The status of dental ultrasound has been thoroughly reviewed by Ghorayeb et al. [14].

We have previously proposed ultrasound as an instrument

Figure. 1. Illustration of buried dental implant fixture placed in the site of the maxillary left central incisor, with overlying soft tissue rendered translucent for visualization by the reader. Uncovery, placement of transgingival abutment, and artificial crown (prosthesis) are yet to be performed.

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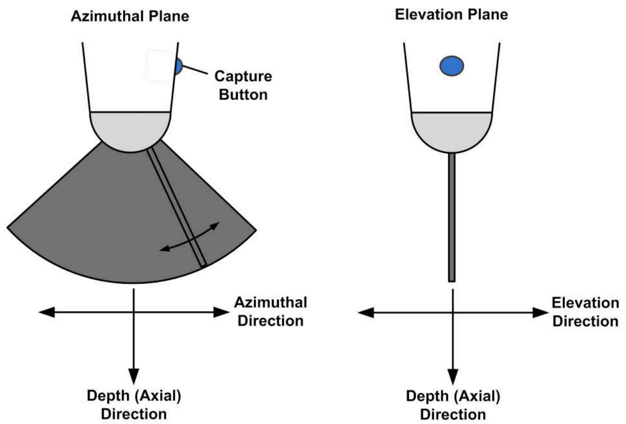

Figure 2. Illustration of ultrasound probe with beam orientations and scan directions.

to detect dental implants and to measure soft tissue thickness using simple pulse-echo measurements [15]. However no such instrument is yet suitable for clinical use or is commercially available. The purpose of this study was to determine whether a 2D ultrasonographic system could be used to detect, locate, and measure dental implants; and to measure the thickness of the overlying soft tissue. To our knowledge, 2D ultrasound imaging of submerged dental implants has not previously been reported.

II. Methods

A. Ultrasound System

A commercially available ultrasound probe (SP 7.5, Interson Corp.), intended for imaging of superficial anatomy in the abdomen, was used to demonstrate the technical feasibility of ultrasound use for this application. The probe was set to 24 MHz in order to provide the maximum spatial resolution afforded by the probe, and to a range of 3 cm. The probe has a required offset of 1 cm, which may be larger than optimal for the *in vivo* dental environment, but allows imaging between gaps between teeth in a partially dentate situation (Fig. 1), and was ideal for *ex vivo* measurements in a water tank. A single-element focused transducer is housed within the probe, and rotates in the azimuthal plane with a 90° sector angle (Fig. 2). The probe was connected to a laptop via USB, and ultrasound image capture software (SeeMore, Interson Corp.) was used to view and collect the imagery.

Figure 3. Porcine jaw specimen, with 4.3 mm anterior implant (left) and 3.5 mm posterior implant (right). Soft tissue was placed over the implants prior to imaging.

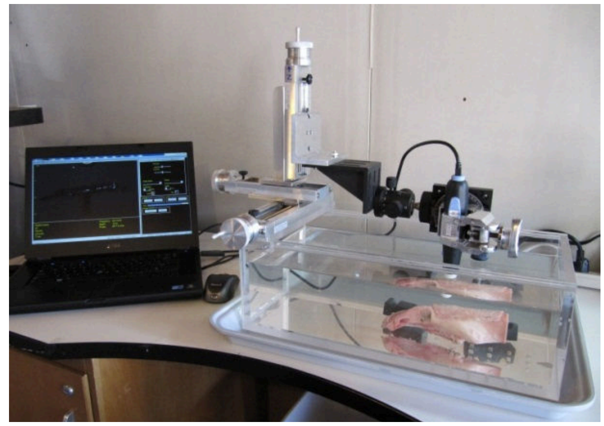

Figure 4. Acoustic test tank, with mechanical translation and rotation stages, clamp to hold ultrasound probe, and ultrasound image provided on laptop display.

B. Porcine Jaw Specimens

Two titanium dental implants were placed in the border of a porcine mandible, simulating a human edentulous ridge, one anteriorly and one posteriorly (Fig. 3). The anterior implant had a 4.3 mm diameter, and the posterior implant had a 3.5 mm diameter, as specified by the manufacturer (Replace Select Tapered, Internal Connection, Nobel Biocare, Yorba Linda, CA). Following placement of the implant, sliced deli turkey, of 1.3 mm thickness, was placed over the implant locations in order to simulate overlying soft tissue, and to blind the examiners. The turkey was attached to the jaw surface using transglutaminase meat glue (Active GS, Ajinomoto U.S.A, Inc., Fort Lee, NJ). The jaw surfaces were first sprayed with water until the desired area was moist, and the meat glue powder was sprinkled evenly onto the moistened area using a tea strainer. The tissue was then wrapped over the desired region and held against the jaw surface for 1 min. Following initial adherence of the soft tissue, the jaw specimen was placed in a refrigerator overnight in order to allow the meat glue to set.

C. Experimental Setup

An acoustic test tank was designed and fabricated that allowed for submersion of the porcine jaw specimens in water and precise translation and rotation of the ultrasound probe about the jaw specimens (Fig. 4). The tank featured X, Y, and Z translation stages (A25 UniSlide, Velmex, Inc., Bloomfield, NY) for accurate translation (± 0.01 mm) in three axes, a rotation stage (13011, Oriel Corp., Irvine, CA, ± 0.1°), and a gimbal (MH-1001, Giottos Industrial, Inc., Taipei, Taiway, ± 5°) which provided accurate rotation in two directions. The mechanical scanning tank was used to determine whether the implants could be detected, to measure implant diameter, to determine the maximum extent of translation and rotation through which the implants could be located, and to measure overlying soft tissue thickness. Three separate experimenters performed each of the four ultrasound measurements.

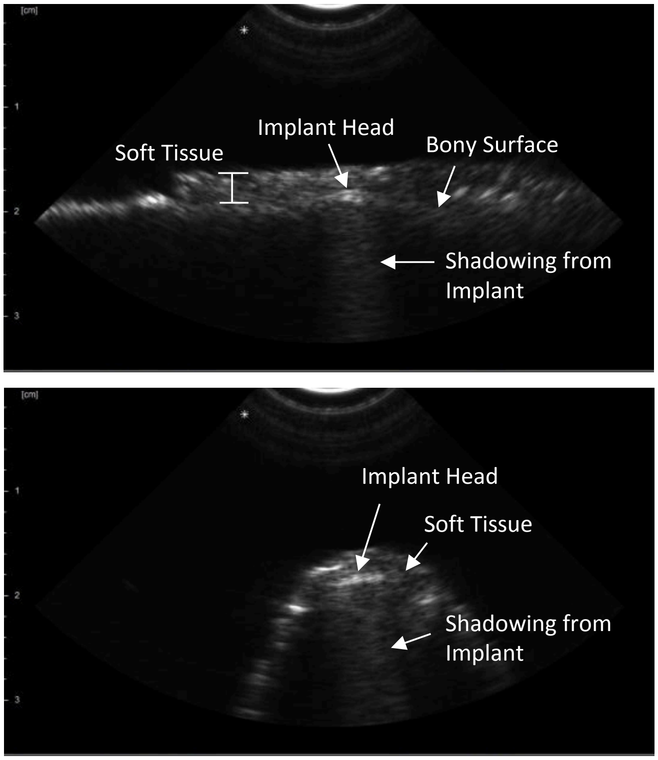

Figure 5. Ultrasound image of posterior implant embedded in the bony crest of a porcine jaw, with the probe oriented in-plane with the bony crest (top), and normal to the bony crest (bottom). All implants were characterized by a bright white reflective cap from the implant head, followed by a long light gray shadow underneath, also known as a "comet-tail artifact."

III. Results and Discussion

Both anterior and posterior implants, as well as their overlying soft tissues, were detected using the ultrasound system in the water tank. This is evident in the two representative ultrasound images in Fig 5, with the ultrasound beam oriented in plane with the porcine bony crest (top image) and normal to the bony crest (bottom image). The soft tissue surface was visible as the upper interface in the ultrasound images, and the bone surfaces were clearly visible as a brighter line below the soft tissue. The distance between the upper interface of the soft tissue to the bright line representing the bone corresponded to the soft tissue thickness.

Both implants were characterized by a bright white reflective cap from the implant head, followed by a long light gray shadow underneath. This shadowing is known in medical ultrasound as a "comet-tail artifact", and is often encountered when highly reflective and specular objects such as glass or metal are present in the acoustic path [16]. Titanium, with an acoustic impedance of 27.3 MRayls, is highly reflective relative to soft tissue (1.63 MRayl, intensity reflection coefficient R = 0.79), and the surface of the implant fixture is polished, and therefore specular. Comet-tail artifacts are caused by reverberations within an object, and can be used to assist clinicians in detecting foreign objects. A repeating band of highly reflective energy creates the shadow, or comet-tail, beyond the surface of the reflector, often with a tail that widens with depth [16].

The mean and standard deviation of the ultrasound-measured implant widths for the anterior and posterior implants, taken from the three experimenters, were 4.6 ± 0.1 mm and 3.8 ± 0.2 mm, respectively, closely matching the manufacturer specified diameters. The ultrasound soft tissue thickness measurements above the anterior and posterior implants were 1.4 ± 0.2 mm and 1.5 ± 0.1 mm, respectively, matching caliper-measured soft tissue thickness to ± 0.3 mm. The caliper measurements were made on the compliant meat after removal from the jaws, so they were a less than perfect gold standard.

When rotating the ultrasound probe using the precision mechanical apparatus, both implants could be detected with a scan angle of ±30° in both the elevation and azimuthal planes. This is evident in the scan sequence provided in Fig. 6, in which the beam was oriented in-plane with the bony crest and the probe was rotated in the azimuthal direction. When translating the probe, both implants were visible over at least 4 mm in the elevation plane and over more than 30 mm in the transverse plane. This is evident in the scan sequence shown in Fig. 7, in which the beam is oriented normal to the bony crest and the probe is translated in the elevation plane. Clinically, these ranges of rotation and translation are expected to be more than sufficient for real-time guidance during implant procedures.

Sometimes many teeth must be replaced, multiple implant fixtures are placed in an edentulous jaw (e.g., Fig. 3), and their positions are more difficult to locate beneath the relatively featureless soft tissue. Alternatively, a single implant fixture may be placed to replace a single missing tooth in an otherwise complete dentition (e.g., Fig. 1), so the general location is known, but the ultrasound probe must be able to identify the detailed hard and soft tissue architecture in a narrow space between adjacent natural teeth, a cluttered environment, but especially important in esthetically prominent areas. The probe design and beam pattern used in this study (Fig. 2) accommodated these different clinical scenarios.

IV. Conclusion

These preliminary results indicate that ultrasound can be used to accurately detect and visualize dental implant fixtures and measure overlying soft tissue thickness in an *ex vivo* environment. If successfully adapted to clinical use, a dental ultrasound instrument may greatly facilitate minimally invasive surgery, a key to the preservation of both soft and hard tissues, as well as facilitatating real time imaging during, and without interrupting, surgical procedures. Current research efforts are focused on expansion of *ex vivo* studies and development of a customized ultrasound tool for clinical use. We believe that this data is a significant first step towards the routine use of ultrasonography in the rapidly growing field of implant therapy.

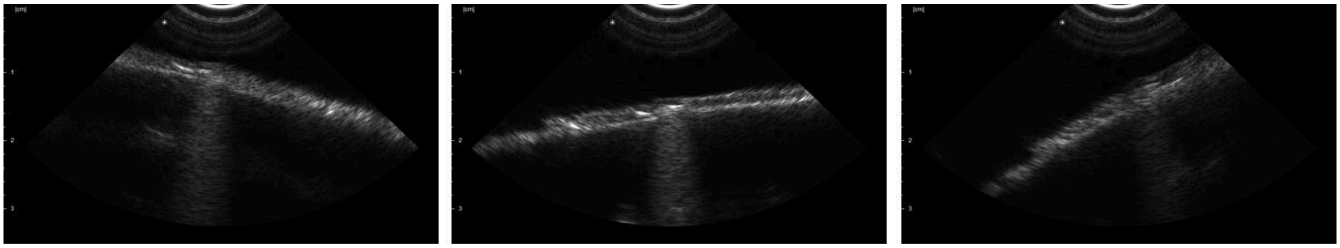

Figure. 6. Azimuthal rotational scan of anterior implant embedded in porcine jaw at -30°, 0°, and +30°, with the probe in the horizontal orientation.

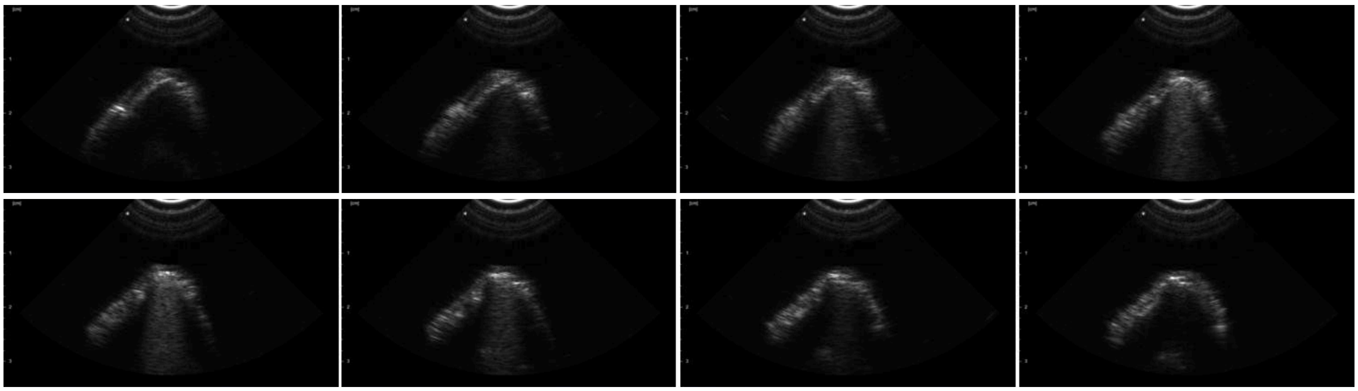

Figure 7. Elevation translational scan of anterior implant embedded in porcine jaw, with step increments of 1 mm, and probe in the vertical orientation. Shadowing from the implant was visible in frames 2-7 (with frames ordered from left to right, top to bottom).

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