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Assessment of gingival thickness using an ultrasonic dental system prototype: A comparison to traditional methods

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ABSTRACT

Knowledge of periodontal anatomy is essential when performing surgical and non-surgical procedures in the field of oral healthcare. Gingival thickness (GT) is often assessed for this purpose. A dental system prototype was recently developed for quantitative, non-invasive GT assessment by high-frequency (HF) ultrasound. Laboratory trials were conducted to validate system performance against a traditional method of assessment.

A system with a 50 MHz broadband, spherically-focused transducer was used. The transducer was housed in a small, hand-held probe equipped with a continuous water supply. A-scans were obtained and thickness at each location was determined. For comparison, the traditional method of transgingival probing through tissue with an endodontic k-file needle was also implemented.

Preliminary experiments were performed on phantoms simulating the anatomical and acoustic properties of human periodontal tissues. A porcine cadaver was obtained for further laboratory trials. The speed of sound through porcine gingiva was determined to be 1564 ± 21 m/s. Finally, a multiple-point experiment involved GT assessment in an array of locations on the buccal gingival surface in the fourth quadrant.

Ultrasonic measurements were found to yield similar GT values to those obtained from invasive methods. Results obtained in this experiment validate the applicability of ultrasound as a diagnostic tool for assessing periodontal anatomy.

1. Introduction

A very important factor influencing the aesthetic outcome of a clinical procedure in dentistry is knowledge of the patient's oral and facial anatomy (Becker et al., 2010; Fanghänel et al., 2006; Tymofiyeva et al., 2013). In particular, the importance of taking into account quantitative differences in gingival thickness (GT) during surgical and non-surgical treatment planning has been widely recognized, due to the fact that thick and thin periodontal biotypes respond differently to inflammation, restorative trauma, and surgical insult (Kao and Pasquinelli, 2002). However, methods currently used to discriminate thin from thick gingiva have limited reliability and accuracy (Cuny-Houchmand et al., 2013). During standard periodontal diagnostic procedures, keratinized and attached gingiva (KT and AG, respectively) and unattached mucosa covering the periodontium are assessed. This knowledge allows the practitioner to adopt the most suitable procedure. In cases where GT is less than 0.7 mm in recipient sites, the translation method should be avoided; preferably, a method using autogenous connective tissue grafting should be implemented (Huang et al., 2005). On the other hand, GT greater than 1.1 mm tends to a greater chance for successful coverage; namely, using the coronal positioned flap method (Hwang and Wang, 2006). In orthodontics, GT assessment prior to the application of orthodontic forces is important as such knowledge can prevent complications arising from gingival recession (Ackerman and Proffit, 1997) (Fig. 1). Other instances include performing controlled guided bone and periodontal tissue regeneration using membranes, and preparing surfaces for denture installation (Savitha and Vandana, 2005). Research has been done including advanced genetic engineering procedures which involve autogenous fibroblasts on a suitable substrate (Dominiak et al., 2012). Further studies to improve and create an alternative procedure for autogenous connective tissue grafts are also underway (Kunert-Keil et al., 2012).

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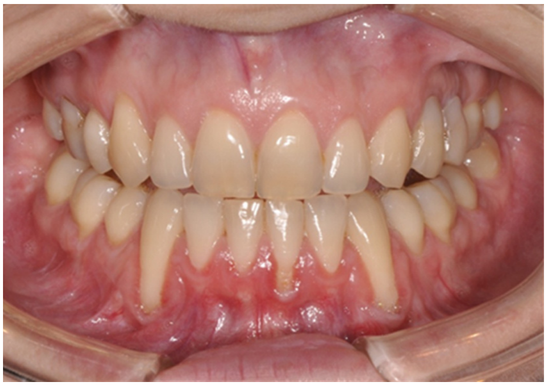

Fig. 1. Multiple advanced recession sites four years after orthodontic treatment.

Several methods are available for GT assessment. For initial diagnosis, a ratio between the length and width of middle incisors is determined, as well as between keratinized gingiva and papilla width (De Rouck et al., 2009; Kan et al., 2010). Another technique which is similar to visual assessment is the transparency method (De Rouck et al., 2009). Although these methods provide valuable information, they do not involve direct measurements. More reliable GT assessment is provided by invasive and non-invasive techniques. A common invasive method involves transgingival probing of locally anesthetized tissue with a k-file endodontic needle (Muller et al., 2000; da Silva et al., 2004; Savitha and Vandana, 2005; Barriviera et al., 2009). Another invasive method is X-ray computed tomography, which does not require anesthesia (Barriviera et al., 2009).

For over a decade, the development of an ultrasonic diagnostic technique to measure oral soft tissue thickness has been underway. Ultrasound has the potential to offer a painless, more accurate and more rapid method of obtaining results compared to traditional invasive methods. The non-invasive GT measurement system investigated in this study utilizes HF ultrasound and operates in pulse-echo mode (Slak et al., 2011). Until recently, a lack of technological progress with regards to both electronics and HF transducers had limited the ability to achieve reliable measurements. Moreover, the majority of research performed with ultrasound has used devices originally designed for applications other than dentistry (Terakura, 1986; Uchida et al., 1989; Muller et al., 1998, 2000).

The system's features and specifications were designed for convenient use in a practitioner's office. The *in vitro* trials performed in this study aim to explore the effectiveness of the developed ultrasonic system as a diagnostic tool in the field of oral healthcare.

2. Materials and methods

2.1. Ultrasonic dental system

A prototype of a compact ultrasonic system was designed and built. This system consists of an analog and digital circuit with a display screen and embedded computer. The hand-held probe is equipped with a 50 MHz ultrasonic transducer built into a pen-like housing. Spherically-shaped polyvinylidene fluoride (PVDF) piezoelectric film was used as the transducer material. The acoustic focal point formed allows one to achieve optimal lateral resolution and accurate localization over the targeted tissue. Water flows continuously through the probe from a small, built-in pump, eliminating the requirement for ultrasonic coupling gel. The entire system can be placed on a small tabletop in the practitioner's office and requires only an external power source. The main advantage of the proposed system over those tested by other groups (Muller et al., 2000; Schulze et al., 2002; Savitha and Vandana, 2005; Denisova et al., 2009; Bednarz, 2011; Bednarz and Zielinska, 2011; Salmon and Le Denmat, 2012; Zimbran et al., 2013) is increased frequency of sound waves, which provides higher axial resolution. Moreover, the water delay line with continuous flow from the probe tip allows measurements to be performed without applying additional pressure to the point of interest. This prevents deformation of the target tissue during ultrasonic assessment, which is essential to obtaining accurate results. In contrast to therapeutic ultrasound tested on periodontal cells (Schuster et al., 2013), this diagnostic system operates at significantly lower energy density and has no biological effect on the site being examined.

The pulse-echo method was applied to obtain ultrasonic measurements. In A-scan mode, an electric signal is sent to the PVDF piezoelectric film where it is converted to a longitudinal sound wave. The wave propagates through the water, which acts as the coupling medium, until it strikes the front gingival surface. Due to the mismatch of acoustic impedance at this interface, part of the pulse is reflected back to the transducer as an echo; here it is converted back into an electric signal, digitized, and displayed as the first peak in the A-scan. The unreflected part of the incident pulse continues to propagate through gingival tissue until it strikes the alveolar bone. At this second interface another echo is created, which returns to the transducer and appears as the second peak in the A-scan. The time lapse between the two echoes returning to the transducer is deemed the time of flight (TOF). TOF is measured by a specially-designed algorithm; by assuming the speed of sound in gingival tissue to be constant, the thickness of the tissue can easily be calculated (Fig. 2).

2.2. Speed of sound determination

A scanning acoustic microscope (Tessonics AM1103, Windsor, ON, Canada) operating in B-scan mode was used to obtain TOF values. A sample of gingiva was excised from the buccal surface in the fourth quadrant. The sample was placed between two parallel, glass microscope slides while immersed in water at 20 °C. Twenty measurements of TOF were taken at equal intervals through both water and tissue.

The speed of sound in water was assumed to be 1482.34 m/s at 20 °C (Briggs, 1992). By having obtained the TOF through water, the distance between the glass slides could be calculated, which was assumed equivalent to the thickness of the gingiva sample. Finally, using this obtained value for thickness along with the measured TOF through tissue, the speed of sound through porcine gingival tissue was determined (Fig. 3).

2.3. Invasive method

For invasive measurements, no.25 k-file endodontic needles were used (Diadent Group Int., Burnaby, BC, Canada). The needle was poked perpendicularly into the gingival surface at the marked location. The limiter remained at the gingival surface while the needle proceeded through the soft tissue until bone or cement was hit. The needle was removed, and the distance between the rubber limiter and the tip of the needle was measured. This was done by taking an up-close picture of the displaced limiter adjacent to a thickness reference block (Albuquerque Industrial, Forest Hills, NY, USA) and using computer software to measure limiter displacement. This distance was taken to be the thickness of the gingiva (Si et al., 2012).

2.4. Phantom experiments

Phantoms were constructed, simulating the anatomical and histological properties of the periodontium. Oral soft tissue was simulated by polyurethane since they have similar ultrasonic