Tissue characterization using optical coherence tomography and cone beam computed tomography: a comparative pilot study

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Objectives. To evaluate the ability of optical coherence tomography (OCT) in differentiating human oral tissues in comparison with cone beam computed tomography.

Study Design. In this study, we imaged four types of tissues ex vivo: human enamel, human cortical bone, human trabecular bone, and fatty tissue plus water and air by using OCT (Axsun Inc., Billerica, MA). We then developed a method for qualitative and quantitative analyses of the human specimens. The same types of tissues were also imaged using cone beam computed tomography, and gray-scale values were measured.

Results. The qualitative indices (intensity profile, contour plot, and histogram) for OCT images were able to provide information regarding surface characteristics as well as changes in tissue properties at different interfaces. The quantitative index (pixel intensity values) was also able to render information regarding the distribution and density of the pixels in different samples. A similar pattern was observed in the pixel intensity values and gray-scale values in both imaging modalities.

Conclusions. Within the limitations of this ex vivo pilot study, OCT can reliably differentiate between a range of hard and soft tissues. (Oral Surg Oral Med Oral Pathol Oral Radiol 2016;122:98-103)

For years, clinicians have been trying to establish accurate and reliable methods to detect and quantify changes in the properties of tissues undergoing pathologic changes. This enables the clinician to better understand the disease process and to detect changes in an early stage, which would result in more successful treatment outcome.[1-3]

It has been well documented that any changes in tissue characteristics resulting from a pathologic or physiologic process affect the tissue attenuation coefficient, tissue echogenicity, tissue diffusion coefficient, and optical properties, which are detectable with the use of computed tomography (CT), ultrasonography (US), magnetic resonance imaging, and optical modalities, respectively.[4-9]

In dentistry, the imaging modality of choice for the majority of procedures is still conventional two-dimensional imaging. With the introduction of cone beam computed tomography (CBCT) in the early 1990s, dental radiology entered a new era, and researchers and manufacturers have been working on improving the image quality, definition, and resolution of the images while reducing the patient's exposure to radiation.[10,11] However, CBCT has a number of limitations, including low-contrast resolution, difficulty in detection of pathologic changes at early stages (i.e., at molecular or cellular levels), and the use of ionizing radiation.[12]

Because of the potential detrimental effects associated with ionizing radiation delivered during CBCT, researchers are working toward developing methods to extrapolate information regarding tissue properties from nonionizing imaging modalities, such as US, magnetic resonance imaging, and optical coherence tomography (OCT).[7,12]

OCT is a noninvasive imaging modality that uses near-infrared light to obtain tissue information at subsurface levels. OCT is analogous to B mode US except that it uses light rather than ultrasound signals, thus achieving unprecedented image resolutions (1−10 μm), approximately 100 times higher than conventional US. OCT has been studied extensively for the detection of

Statement of Clinical Relevance

Optical coherence tomography is a noninvasive imaging modality that provides near-histology resolution images. If it proves to be able to detect pathologic changes at early stages based on changes in tissue properties, it can lead to better treatment outcomes.

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Received for publication Jul 16, 2015; returned for revision Mar 15, 2016; accepted for publication Mar 29, 2016.

2212-4403/$ - see front matter
http://dx.doi.org/10.1016/j.oooo.2016.03.021

early carious lesions, microfractures, pulpal inflammation, properties of dental materials, early dysplastic changes in oral malignancies, early inflammatory changes in the periodontal tissues, and periodontal ligament changes caused by orthodontic tooth movement.[13-23]

Extensions of OCT have been developed that enable noninvasive, depth-resolved functional or contrast-enhanced imaging, providing spectroscopic, metabolic, polarization-sensitive, blood flow, or physiologic tissue information. These new OCT technologies promise not only to improve image contrast but also to enable the differentiation of pathology using localized metabolic properties of the functional state.

In dentistry, there is limited information on optical coherence spectroscopy and tissue characterization with the use of optical imaging. Therefore, the purpose of this study was to evaluate the ability of OCT to characterize selected samples of hard and soft tissues in the oral cavity in comparison with representative gray-scale values in CBCT.

MATERIALS AND METHODS

In this comparative observational study, we attempted to evaluate the ability of OCT for oral tissue characterization for a range of biologic tissues. We then compared the values obtained from OCT images with gray-scale values of the same tissue obtained from CBCT volumes. The study was done in two phases.

Phase 1: imaging with optical coherence tomography

Four different tissues (fatty tissue, ex vivo human cancellous bone, ex vivo human cortical bone, and ex vivo human enamel) were prepared in blocks of 5 × 5 × 3 mm (width × length × height). Water was poured into a container with similar dimensions. The surfaces of the tissues were kept hydrated for optimal light penetration and refraction.[24] The OCT imaging system that was used in the present study was a prototype OCT unit provided by Axsun Technologies Inc. (Billerica, MA). It is a swept source OCT system operating at wavelengths ranging between 1250 nm and 1360 nm with an average power of 18 mW and a scan rate of 50 to 100 kHz.

The probe was placed on top of a 2 × 2 cm stabilizing device to maintain a standard distance from the samples. Ten image samples from each type of tissue were obtained. To acquire images with minimum inhomogeneity, imaging was performed multiple times at different points. Images with the least heterogeneous presentation were imported and saved in PNG (portable network graphics) format. The mean pixel intensity values for each image were calculated by using MATLAB (Matrix Laboratory). In addition, the contour plot and histogram for each image were extrapolated. The pixel intensity values were determined on the basis of the distribution and the density of the pixels within the image. The contour plots provided information regarding changes in boundaries in the imaged portion of the sample. Each pixel within a certain range of density was assigned a color, and any changes in density or surface irregularities were demonstrated as a change in color. The histograms provided information regarding the distribution of pixels along the gray-scale.

Phase 2: imaging with cone beam computed tomography

The same types of tissues were scanned by using 3-D Accuitomo 170 CBCT scanner (J Morita Corp., Kyoto, Japan) operating at 80 KVp and 5 mA with a focal spot size of 0.5 mm. The image acquisition time was 17.5 seconds, and the field of view was 40 × 40 mm. The machine has three modes of acquisition: standard (scan time: 17.5 seconds), high resolution (scan time: 30.8 seconds) and high fidelity (scan time: 30.8 seconds). In this study, we used the standard mode. The volumes were then reconstructed in the i-Dixel software, version 2.1, and exported into the Invivo software, version 5.0 (Anatomage 3-D, San Jose, CA) for gray-scale evaluation. The gray-scale value was measured in three areas within each sample and the mean value was reported.

RESULTS

Figure 1 illustrates a representative OCT image along with the corresponding CBCT image, contour plot, and histogram for air, water, fatty tissue, trabecular bone, cortical bone, and enamel, respectively. The purpose of using the contour plot and histogram was to extract some morphologic features from OCT images to differentiate between different oral tissues. The vertical line in the OCT image indicates that the scan was done longitudinally along the depth of the samples. The contour plots of air and water (see Figure 1C and 1G) show a homogeneous pattern of the distribution of pixels. However, the density of the plots varies between air and water, which is likely caused by the differences in the scatter coefficient of these two samples. The histograms for air and water show a relatively homogeneous pattern with pixels concentrated in the dark end of the gray-scale (see Figure 1D and 1H). The contour plots for fatty tissue, trabecular bone, cortical bone, and enamel show changes in tissue interfaces within one tissue sample (see Figure 1K, 1O, 1S, and 1W). The corresponding histograms for these tissues also demonstrate a