3D Reconstructions of resin dental fillings based on en face OCT images

Florin I. Topală, Cosmin Sinescu, Meda L.Negruţiu, Adrian Bradu, Mihai Rominu, Adrian Gh. Podoleanu

Abstract— Optical tomographic techniques are of particular importance in the medical imaging field, because these techniques can provide non-invasive diagnostic images. In the present study, en-face optical coherence tomography (enOCT) was used as a non-invasive high resolution imaging method for supplying the necessary information on the quality of dental hard tissues and coronal composite resin fillings. Teeth after being subject to several treatment methods are imaged in order to assess the material defects and micro-leakage of tooth-filling interface as well as to evaluate the quality of dental hard tissue. C-scan and B-scan OCT images are acquired from a large range of samples. Based on such images, 3D reconstructions were assembled, which lead to a better view of the investigated areas. Cracks and voids in the dental structures as well as material defects and gaps at the interfaces are clearly exposed.

The advantages of the OCT imaging method consist in non-invasiveness and high resolution. The en-face OCT offers the user the possibility of rapidly acquiring sequential B-scans and C-scans by switching the instrument between the two regimes. Sequential and rapid switching between the en-face regime and the cross-section regime, specific for the en-face OCT systems, represent a significant advantage in the process of non-invasive imaging, as images with different orientations can be obtained using the same system, during the same imaging event. 3D reconstructions of volumes allow evaluation and localization of defects in the samples. By importing such data into numerical simulation software can provide answers on the behavior of the investigated structures.

Keywords— optical coherence tomography, 3D reconstructions, dental hard tissues, composite resin dental fillings

I. INTRODUCTION

OCT is an emerging technology, representing a paradigm shift over conventional light microscopy. It is a tomographic imaging technology capable of producing high-resolution cross-sectional images of the internal architecture of materials in a non-invasive manner1. OCT was first proposed for use as a biological imaging system in 1991 by Huang and colleagues2. The light is able to penetrate the sensitive structures without harmful effects. Differences in the reflection of light are used to generate a signal corresponding to the morphology and composition of the underlying layers. The penetration depth depends on the optical properties of the material. The slices collected can be assembled into three dimensional structures that lead to a better view of the investigated areas. By importing the data into numerical simulation software, we can non-invasively evaluate the behaviour of the investigated structures. The resolution range of OCT lies between confocal microscopy and ultrasound imaging.

En-face OCT is preferred for microscopy as it can provide real time images with similar orientation as that of microscopy images. A system equipped with a pigtailed superluminescent diode (SLD) emitting at 1300 nm with a spectral bandwidth of 65 nm was used, which determined an OCT longitudinal resolution of around 17.3 µm in tissue3. The light can non-invasively evaluate the behaviour of the investigated structures. The resolution range of OCT lies between confocal microscopy and ultrasound imaging.

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An important goal in conservative dentistry is the evaluation of the dental hard tissue and the quality of fillings. The usual methods for assessing marginal micro-leakages are invasive and are performed in vitro only4,5.

In dentistry, OCT was successfully used for acquiring images of incipient6,7, and advanced carious lesions6,7,8,9 OCT images...
have proven useful in the evaluation of remineralization\textsuperscript{10, 11} and in determining the efficiency of chemical agents used for the inhibition of the demineralization\textsuperscript{7, 8}. OCT was also used for testing the inhibition of demineralization in an in vitro simulated caries model due to different fluoride agents, on smooth enamel surfaces peripheral to orthodontic brackets for evaluating the demineralized white lesions surrounding orthodontic brackets and orthodontic interfaces\textsuperscript{13}, for determining tooth movement under light orthodontic forces\textsuperscript{14}. OCT was also reported in the evaluation of the oral mucosa\textsuperscript{9, 17, 18}, the dental implant status\textsuperscript{9, 17, 19, 20}, the dental hard tissue. Figure 2 shows the 3D reconstruction. For group A, teeth without treatment are imaged (fig.1), in order to assess the quality of the dental hard tissue. We found cracks and demineralization areas (fig.1 b) in the depth of the dental hard tissue. Figure 2 shows the 3D reconstruction.

II. METHODOLOGY

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III. RESULTS

For group A, teeth without treatment are imaged (fig.1), in order to assess the quality of the dental hard tissue. We found cracks and demineralization areas (fig.1 b) in the depth of the dental hard tissue. Figure 2 shows the 3D reconstruction.

Fig1. OCT investigation of tooth without dental treatment: a. the investigated area; b. C-scan image acquired from the investigated area. Size of images required

Fig2. 3D reconstruction of the investigated area of a tooth without treatment

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
<th>Conversion from Gaussian and CGS EMU to SI a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ</td>
<td>magnetic flux</td>
<td>1 Mx → 10⁻⁶ Wb = 10⁻⁸ V·s</td>
</tr>
<tr>
<td>B</td>
<td>magnetic flux density, magnetic induction</td>
<td>1 G → 10⁻⁴ T = 10⁻⁶ Wb/m²</td>
</tr>
<tr>
<td>H</td>
<td>magnetic field strength</td>
<td>1 Oe → 10¹/(4π) A/m</td>
</tr>
<tr>
<td>m</td>
<td>magnetic moment</td>
<td>1 erg/G = 1 emu</td>
</tr>
<tr>
<td>M</td>
<td>magnetization</td>
<td>1 erg/(G·cm³) = 1 emu/cm³ → 10⁻⁹ A/m</td>
</tr>
<tr>
<td>4πM</td>
<td>magnetization</td>
<td>1 G → 10⁹/(4π) A/m</td>
</tr>
<tr>
<td>σ</td>
<td>specific magnetization</td>
<td>1 erg/(G·g) = 1 emu/g → 1 A·m²/kg</td>
</tr>
<tr>
<td>j</td>
<td>magnetic dipole moment</td>
<td>1 erg/G = 1 emu</td>
</tr>
<tr>
<td>J</td>
<td>magnetic polarization</td>
<td>1 erg/(G·cm³) = 1 emu/cm³ → 4π × 10⁻⁴ T</td>
</tr>
<tr>
<td>Z, κ</td>
<td>susceptibility</td>
<td>1 → 4π</td>
</tr>
<tr>
<td>Zp</td>
<td>mass susceptibility</td>
<td>1 cm³/g → 4π × 10⁻³ m³/kg</td>
</tr>
<tr>
<td>μ</td>
<td>permeability</td>
<td>1 → 4π × 10⁻¹ H/m → 4π × 10⁻³ Wb/(A·m)</td>
</tr>
<tr>
<td>μr</td>
<td>relative permeability</td>
<td>μ → μr</td>
</tr>
<tr>
<td>w, W</td>
<td>energy density</td>
<td>1 erg/cm³ → 10⁻¹ J/m³</td>
</tr>
<tr>
<td>N, D</td>
<td>demagnetizing factor</td>
<td>1 → 1/(4π)</td>
</tr>
</tbody>
</table>

No vertical lines in table. Statements that serve as captions for the entire table do not need footnote letters.

\textsuperscript{a}Gaussian units are the same as cgs emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.
**IV. DISCUSSIONS**

*En-face* OCT images have been generated from a depth of up to 1.5 mm. Cavities filled with composite resin have been imaged, showing voids within the restorative material. These may occur due to inadequate condensation. Also, gaps were visible at the tooth – restorative material interface which are expected to reduce the time-resistance of the filling and increase the risk of secondary caries occurrence. The interface between the dental structure and the filling composite resin is well distinguished. We can also make difference between the granular structure of the composite resin and the dental tissue. Because the interface is well seen, we can also visualize any defect which might exit here, or extend into the material. In addition, in the inferior part of the composite filling, we can distinguish an interface with good contrast due to demineralization.

The gap failure in a restored tooth can be evaluated by the OCT technique, and with a system resolution of 10 µm we were able to detect gaps, as small as 50 µm. Imaging gaps narrower than 10 µm requires improvements in our incoherent light source. Furthermore, the use of OCT has the advantage of showing the restored region as well as the gap, if it exists, and it allows precise localization of its position, as demonstrated here. Exploration of the recent advances in OCT in terms of different excitation wavelengths and wider bandwidths can lead to state-of-the-art imaging systems in odontology, enabling imaging of both enamel and dentin. Finally, as demonstrated in the literature, *in vivo* and real-time OCT images can be obtained, and therefore this method of assessment is potentially useful for clinical diagnostics.

**V. CONCLUSION**

OCT has numerous advantages which justify its use in the oral cavity in comparison with conventional dental imaging.

OCT can achieve the best depth resolution of all known methods (in principle 1 micron if the source exhibits a sufficiently wide spectrum) and is safe. The OCT method presents potential for real time *in vivo* investigation of the restorative treatments.

Sequential and rapid switching between the *en-face* regime and the cross-section regime, specific for the *en-face* OCT systems, represent a significant advantage in the non-invasive imaging as images with different orientations can be obtained using the same system.

3D reconstruction of the acquired images permit volume evaluation and localization of defects of the investigated areas.

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