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

Florin I. Topală, Cosmin Sinescu, Meda L.Negruțiu, 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 (*ef*OCT) 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 asses 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 manner[1]. OCT was first proposed for use as a biological imaging system in 1991 by Huang and colleagues[2].

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 tissue[3].

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* only[4,5].

In dentistry, OCT was successfully used for acquiring images of incipient[6,7] and advanced carious lesions[6,7,8,9]. OCT images

Manuscript received November 12, 2010. This work was supported in part by the Ministry of Education in Romania under CNCSIS research grant for Young Teams Nr.101/2010.

Florin I. Topală is with the Faculty of Dentistry, University of Medicine and Pharmacy "Victor Babeş" Timişoara, Romania (corresponding author to provide e-mail: florin.topala@gmail.com).

Cosmin Sinescu is with the Faculty of Dentistry, University of Medicine and Pharmacy "Victor Babeş" Timişoara, Romania (corresponding author to provide e-mail: florin.topala@gmail.com).

Meda L.Negruțiu is with the Faculty of Dentistry, University of Medicine and Pharmacy "Victor Babeş" Timişoara, Romania (corresponding author to provide e-mail: florin.topala@gmail.com).

Adrian Bradu is with the Applied Optics Group, School of Physical Sciences, University of Kent, Canterbury, UK (corresponding author to provide e-mail: florin.topala@gmail.com).

Mihai Rominu is with the Faculty of Dentistry, University of Medicine and Pharmacy "Victor Babeş" Timişoara, Romania (corresponding author to provide e-mail: florin.topala@gmail.com).

Adrian Gh. Podoleanu is with the Applied Optics Group, School of Physical Sciences, University of Kent, Canterbury, UK (corresponding author to provide e-mail: florin.topala@gmail.com).

have proven useful in the evaluation of remineralization[10,11] and in determining the efficiency of chemical agents used for the inhibition of the demineralization[12]. 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[13], for determining tooth movement under light orthodontic forces[14]. OCT was also reported in the evaluation of the oral mucosa[5], of the microleakage of dental restorations and endodontic fillings[15], the dental implant status[16], the integrity of dental prosthesis[9,17, 18], their quality and their marginal fitting[7,9,19, 20].
In the present study, *en-face* optical coherence tomography (efOCT) 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.

## II. Methodology

### A. Review Stage

Please submit your manuscript electronically for review as e-mail attachments.

### B. Final Stage

When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

### C. Figures

All tables and figures will be processed as images. **However, NAUN cannot extract the tables and figures embedded in your document.** The figures and tables you insert in your document are only to help you gauge the size of your paper, for the convenience of the referees, and to make it easy for you to distribute preprints.

### D. Document Modification

If you modify this document for use with other **NAUN**, journals or conferences, you should save it as type "Word - RTF (*.doc)" so that it can be opened by any version of *Word.*

### E. Copyright Form

A **NAUN** copyright form should accompany your final submission. You can get a .pdf, .html, or .doc version at http://www.enformatika.org/copyright.doc or from the first issues in each volume of the **NAUN**. Authors are responsible for obtaining any security clearances.

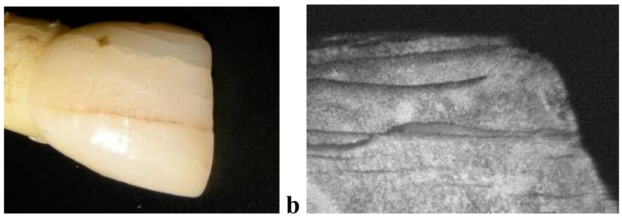
## III. Results

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.

TABLE I
UNITS FOR MAGNETIC PROPERTIES

| Symbol | Quantity | Conversion from Gaussian and CGS EMU to SI [a] |
|---|---|---|
| $\Phi$ | magnetic flux | 1 Mx → $10^{-8}$ Wb = $10^{-8}$ V·s |
| $B$ | magnetic flux density, magnetic induction | 1 G → $10^{-4}$ T = $10^{-4}$ Wb/m$^2$ |
| $H$ | magnetic field strength | 1 Oe → $10^3/(4\pi)$ A/m |
| $m$ | magnetic moment | 1 erg/G = 1 emu → $10^{-3}$ A·m$^2$ = $10^{-3}$ J/T |
| $M$ | magnetization | 1 erg/(G·cm$^3$) = 1 emu/cm$^3$ → $10^3$ A/m |
| $4\pi M$ | magnetization | 1 G → $10^3/(4\pi)$ A/m |
| $\sigma$ | specific magnetization | 1 erg/(G·g) = 1 emu/g → 1 A·m$^2$/kg |
| $j$ | magnetic dipole moment | 1 erg/G = 1 emu → $4\pi \times 10^{-10}$ Wb·m |
| $J$ | magnetic polarization | 1 erg/(G·cm$^3$) = 1 emu/cm$^3$ → $4\pi \times 10^{-4}$ T |
| $\chi$, $\kappa$ | susceptibility | 1 → $4\pi$ |
| $\chi_\rho$ | mass susceptibility | 1 cm$^3$/g → $4\pi \times 10^{-3}$ m$^3$/kg |
| $\mu$ | permeability | 1 → $4\pi \times 10^{-7}$ H/m = $4\pi \times 10^{-7}$ Wb/(A·m) |
| $\mu_r$ | relative permeability | $\mu \to \mu_r$ |
| $w$, $W$ | energy density | 1 erg/cm$^3$ → $10^{-1}$ J/m$^3$ |
| $N$, $D$ | demagnetizing factor | 1 → $1/(4\pi)$ |

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



a b

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

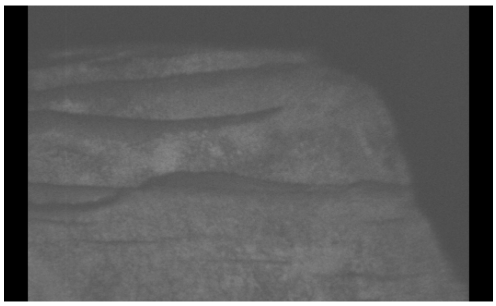
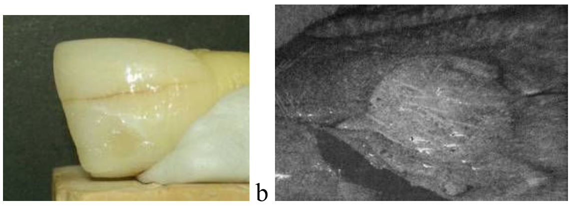


Fig2. 3D reconstruction of the investigated area of a tooth without treatment

For group B, teeth with several treatment methods are imaged, in order to assess the material defects and micro-leakage at the tooth-filling interfaces. Figure 3 shows an *en-face* OCT image acquired from samples with composite resin filling. The 3D reconstruction is presented in figure 4.

ISBN: 978-960-474-261-5



a b

Fig.3. *En-face* OCT investigation at various depths of a diacrylic composite resin filling of a sample probe: **a.** the investigated area; **b.** C-scan image aquired from the investigated area.

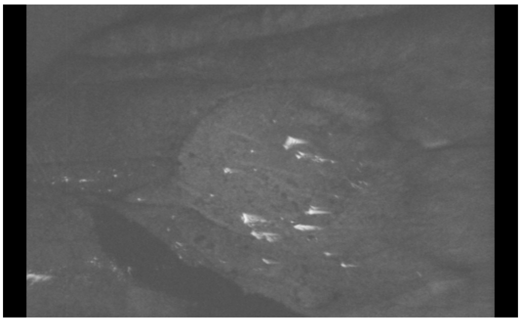


Fig.4. 3D reconstruction of the investigated area of a tooth with composite resin filling

## 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 defectwhich might exit here, or extend inside 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.

## ACKNOWLEDGMENT

Author thanks to the Ministry of Education in Romania under CNCSIS research grant for Young Teams Nr.101/2010

## REFERENCES

[1] Mason C, Markusen JF, Town MA, Dunnill P and Wang RK. The potential of optical coherence tomography in the engineering of living tissue. Phys. Med. Biol. 2004; 49: 1097-1115;

[2] Huang D., Swanson E. A., Lin C. P., Schuman J. S. et al. Optical coherence tomography, Science 254 (1991):1178-1181.

[3] Podoleanu A. Gh., Rogers J.A., Jackson D.A. and Dunne S., “Three dimensional OCT images from retina and skin” *Opt. Express*, Vol. 7, No. 9, p. 292-298, (2000) http://www.opticsexpress.org/framestocv7n9.htm;

[4] Nozaka K., Suruga Y., Amari E., “Microleakage of composite resins in cavities of upper primary molars,” *International Journal of Paediatric Dentistry*, 9:185-94 (1999);

5 Delme K.I.M., Deman P.J., De Moor R.J.G., “Microleakage of class V resin composite restorations after conventional and Er:YAG laser preparation,” Journal of Oral Rehabilitation, 32: 676-685 (2005);

[6] F. I. Feldchtein, G. V. Gelikonov, V. M. Gelikonov, R. R. Iksanov, R. V. Kuranov, A. M. Sergeev, In vivo OCT imaging of hard and soft tissue of the oral cavity, Optics Express 3(6), (1998).

[7] B. W. Colston, Jr., U. S. Sathyam, L. B. DaSilva and M. J. Everett, Dental OCT, Optic Express, 3(6):230-238 (1998).

[8] B.T. Amaechi, A. Podoleanu, S.M. Higham and D.A. Jackson, “Correlation of quantitative light-induced fluorescence and optical coherence tomography applied for detection and quantification of early dental caries,” Journal of Biomedical Optics 8 (4), 642-647 (2003)

[9] Cosmin Sinescu, Meda Lavinia Negrutiu, Carmen Todea, Cosmin Balabuc, Laura Filip, Roxana Rominu, Adrian Bradu,

Michael Hughes and Adrian Podoleanu, Quality assessment of dental treatments using en-face optical coherence tomography, Journal of Biomedical Optics, Vol. 13(5), (2008).
[10] Sherri L. Chong, Cynthia L. Darling, Daniel Fried, Nondestructive Measurement of the Inhibition of Demineralization on Smooth Surfaces Using Polarization-Sensitive Optical Coherence Tomography. Lasers in Surgery and Medicine, 39:422–427 (2007)
[11] Sherri Lyn Chong. Detection of white spot lesions around orthodontic brackets using polarization-sensitive optical coherence tomography. Am J Orthod Dentofacial Orthop; 132: 711 (2007).
[12] Philip Edward Bensona, Anwar Ali Shahb, Derrick Robert Willmotc, Polarized Versus Nonpolarized Digital Images for the Measurement of Demineralization Surrounding Orthodontic Brackets. Angle Orthodontist, Vol 78(2), (2008).
[13] R. O. Rominu, C. Sinescu, D.M. Pop, M. Hughes, A. Bradu, M. Rominu, A. Gh. Podoleanu, En-Face Optical Coherence Tomography and Fluorecence in Evaluation of Orthodontic Interfaces. World Academy of Science, Engineering and Technology 56, (2009).
[14] Jihoon Na, Byeong Ha Lee, Jae Ho Baek, Eun Seo Choi, Optical aproach for monitoring the periodontal ligament changes induced by orthodontic forces around maxillary anterior teeth of white rats. Med Biol Eng Comput, 46:597–603 (2008)
[15] Carmen Todea, Cosmin Balabuc, Cosmin Sinescu, Laura Filip, Cristina Kerezsi, Mircea Calniceanu, Meda Negrutiu, Adrian Bradu, Michael Hughes, Adrian Gh. Podoleanu, En face optical coherence tomography investigation of apical microleakage after laser-assisted endodontic treatment, Lasers Med Sci (2009).
[16] Cosmin Sinescu, Michael Huges, Adrian Bradu, Meda Negrutiu, Sergiu Antonie, Philippe Laissue, Mihai Rominu, Adrian G. Podoleanu, Implant bone interface investigated with a non-invasive method: optical coherence tomography, Biophotonics: Photonic Solutions for Better Health Care, Proc. SPIE, Vol. 6991, 69911L-1 – 69911L-9 (2008).
[17] Meda L.Negrutiu, Cosmin Sinescu, Carmen Todea, Adrian G. Podoleanu, Complete denture analyzed by optical coherence tomography, Laser in Dentistry XIV, Proc. SPIE, Vol. 6843, 68430R-1 – 68430R-8 (2008).
[18] Meda L.Negrutiu, Cosmin Sinescu, Michael Hughes, Adrian Bradu, Luciana Goguta, Mihai Rominu, Radu Negru and Adrian Gh. Podoleanu, Fibres reinforced dentures investigated with en-face optical coherence tomography, Biophotonics: Photonic Solutions for Better Health Care, Proc. SPIE, Vol. 6991, 69911U-1 – 69911U-6 (2008).
[19] Cosmin Sinescu, Meda Negrutiu, Carmen Todea, Mike Hughes, Florin Tudorache, Adrian Gh. Podoleanu, Fixed partial denture investigated by optical coherence tomography, Coherence Domain Optical Methods and Optical Coherence Tomography in Biomedicine XII, Proc. SPIE, Vol. 6847, 684707-1 – 684707-10 (2008).
[20] Cosmin Sinescu, Meda Negruțiu, Emanuela Petrescu, Mihai Rominu, Corina Mărcăuțeanu, Enikö Demjan, Mike Hughes, Adrian Bradu, George Dobre, Adrian Gh. Podoleanu, Marginal adaptation of ceramic veneers investigated with en-face optical coherence tomography, Proc. SPIE, Vol. 7372, 73722C (2009).