Confocal Microscopy Combined with Time Domain Optical Coherence Tomography and Micro Computer Tomography in Interface Evaluation of Class II Direct Composite Restoration

COSMIN SINESCU[1], LIVIU MARSAVINA[2], MEDA-LAVINIA NEGRUTIU[1]*, LAURA-CRISTINA RUSU[1], LAVINIA ARDELEAN[1], CIPRIAN IONITA[3], ADRIAN GH. PODOLEANU[4], MIHAI ROMINU[1], FLORIN-IONEL TOPALA[1]

[1]University of Medicine and Pharmacy Victor Babes from Timisoara, 9 Revolutiei 1989 Blv., 300070, Timisoara, Romania
[2]University of Politehnica from Timisoara, 2 Pta. Victoriei, 300006, Timisoara, Romania
[3]University at Buffalo, School of Medicine and Biomedical Sciences, New York, USA
[4]University of Kent, Canterbury, UK

Class II cavities are often a challenge for dentists. There are a lot of procedures that can be used in order to fill this type of cavity and also a lot of problems concerning marginal adaptation, especially when composite materials are used. The aims of this study are to evaluate the integrity and marginal adaptation of class II direct composite fillings. There were used 32 samples for orthodontic reasons. Metallographic evaluation was used as the invasive methods. Micro computer tomography, confocal microscopy and optical coherence tomography were used as noninvasive methods. The conclusions pointed out the fact that noninvasive evaluation methods have great capability to accomplish a high quality characterization of the class II direct composite restorations.

Keywords: class II cavities, direct composite fillings, optical coherence tomography, confocal microscopy, micro computer tomography

Restoring a class II preparation with composite resin is challenging [1]. For the evaluation of marginal adaptation in class II composite restorations, several methods have been developed (bacterial penetration, fluid transport, clarification, penetration of radioisotopes, electrochemical methods and gas chromatography). Dye penetration tests (microleakage tests) however, are to be the most widely used due to their ease of application and low costs. Their main disadvantage is that the samples are sectioned. The test of microleakage at the tooth–restorative interface using various penetrating dyes has been widely used due to its ease of application. The results however, are subject, partly or totally to different influences of the methods that are applied. In addition, the comparison of results obtained by different authors is difficult and may even lead to doubtful interpretation [2].

Along with the well known dye penetration technique, optical coherence tomography (OCT) working in Time Domain was used for detection of voids and gaps at the interfaces which could have an impact on both the marginal seal and microleakage [3- 6]. To our knowledge this method was never employed before in the study of the marginal seal between composite and tooth structure in class II cavities. The purpose of this study is to present an alternative non invasive/non destructive method instead of the dye penetration evaluation.

Experimental part

32 human extracted teeth crack-free were randomly selected for this study. The teeth were stored in physiological saline solution prior to use. A standardized class II cavity was prepared on the surface of each tooth using a regular grit fissure diamond bur (no. 835, ISO 806 314 108 524 018, (Germany). The cavities were conditioned as follows: total acid etching, 15 s with 37.5% phosphoric acid Gel Etchant (Kerr), than aplication of OptiBond Solo Plus (Kerr) adhesive. All cavities were bulk filled with Premise (Kerr) composite. All materials were used according to manufacturer's instructions. The composite restorations were finished and polished, using a fine grit diamond bur (no. 858F, ISO 806 314 165 514 014, (Germany) and Kerr-Hawe polishing discs (Germany). The specimens were then stored one week in distilled water (37°C) and thermocycled (1000 cycles) with a dwell time of 25 s in each bath (transit time 5 s) between 5-55 °C. The restored teeth were stored in distilled water (7 days).

The interfaces were examined by the Optical Coherence Tomography method (OCT) combined with the confocal microscopy (fig. 1). The optical configuration uses two single mode directional couplers with a superluminiscent diode as the source at 1300 nm. The scanning procedure is similar to that used in any confocal microscope, where the fast scanning is en-face (line rate) and the depth scanning is much slower (at the frame rate). In time domain OCT the path length of the reference arm is translated longitudinally in time. A property of low coherence interferometry is that interference, i.e. the series of dark and bright fringes, is only achieved when the path difference lies within the coherence length of the light source. This interference is called auto correlation in a symmetric interferometer (both arms have the same reflectivity), or cross-correlation in the common case. The envelope of this modulation changes as path length difference is varied, where the peak of the envelope corresponds to path length matching. The interference of two partially coherent light beams can be expressed in terms of the source intensity, I_S, as

$$I = k_1 I_S + k_2 I_S + 2\sqrt{(k_1 I_S) \cdot (k_2 I_S)} \cdot Re\,[\gamma(\tau)] \quad (1)$$

* email: **meda_negrutiu@yahoo.com: Tel.:** 0040 722700593

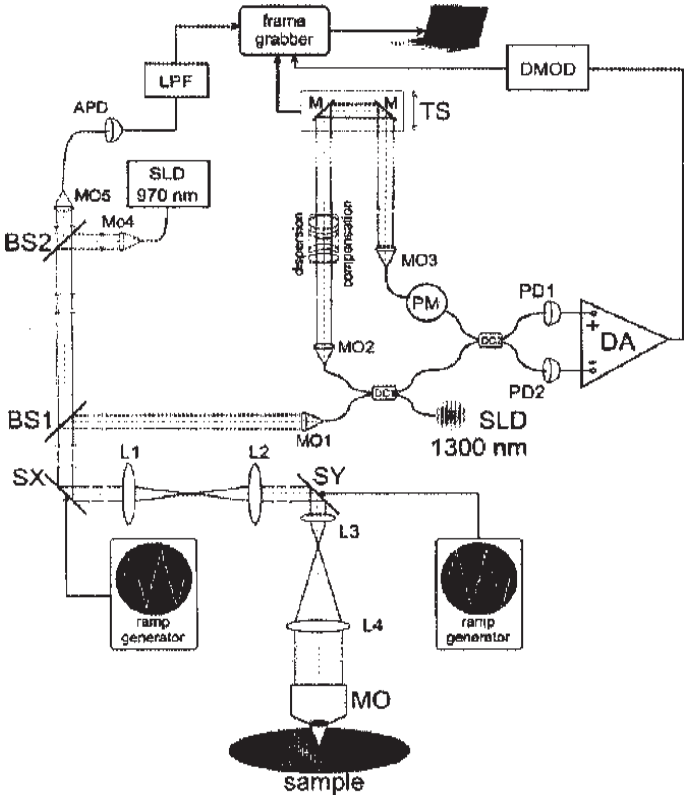

Fig. 1. Optical coherence tomography system architecture

where $k_1 + k_2 < 1$ represents the interferometer beam splitting ratio, and $\gamma(\tau)$ is called the complex degree of coherence, i.e. the interference envelope and carrier dependent on reference arm scan or time delay τ, and whose recovery of interest is in OCT. Due to the coherence gating effect of OCT the complex degree of coherence is represented as a Gaussian function expressed as

$$\gamma(\tau) = \exp\left[-\left(\frac{\pi\Delta\nu\tau}{2\sqrt{\ln 2}}\right)^2\right] \cdot \exp(-j2\pi\nu_0\tau) \quad (2)$$

where $\Delta\nu$ represents the spectral width of the source in the optical frequency domain, and ν_0 is the central optical frequency of the source. In equation (2), the Gaussian envelope is amplitude modulated by an optical carrier. The peak of this envelope represents the location of sample under test microstructure, with amplitude dependent on the reflectivity of the surface. The optical carrier is due to the Doppler Effect resulting from scanning one arm of the interferometer, and the frequency of this modulation is controlled by the speed of scanning. Therefore translating one arm of the interferometer has two functions; depth scanning and a Doppler-shifted optical carrier are accomplished by path length variation. In OCT, the Doppler-shifted optical carrier has a frequency expressed as

$$f_{Dopp} = \frac{2 \cdot \nu_0 \cdot v_s}{c} \quad (3)$$

where ν_0 is the central optical frequency of the source, v_s is the scanning velocity of the path length variation, and c is the speed of light interference signals in TD vs. FD-OCT. The axial and lateral resolutions of OCT are decoupled from one another; the former being an equivalent to the coherence length of the light source and the latter being a function of the optics.

The samples were scanned using cone beam micro-CT. The cone-beam micro-CT scanner consists of a micro-focal spot x-ray tube (10-20 μm), xyz+rotary stage, and a micro-angiographic detector with a 45 microns pixel size. The x-ray exposure parameters were: 40 kVp, 1 mA and 300 ms exposure per frame. The samples were placed onto the rotary stage at a magnification between 2 and 1.1 depending on the sample size and scanned using one degree step increments. After projection acquisition they were reconstructed using a $(512)^3$ volume with a 45 microns^3 per voxel.

Results and discussions

All the samples were investigated by OCT combined with Confocal Microscopy in order to evaluate the surface of the interfaces. The confocal channel operates at a different wavelength than that of the OCT, to allow the utilization of a high gain silicon avalanche photodiode. Light from a superluminscent diode at 970 nm is collimated by a microscope objective and reflected by a splitter. In the picture it is revealed a C scan investigation of class II resin filled cavity. The scanning procedures of OCT working in Time Domain revealed good and open interfaces between resin composite fillings and dental structures. Almost all the samples presented open interfaces combined with good (closed) interfaces (fig. 2). In some samples only open interfaces were observed (fig. 3).

In order to a better understanding of the interfaces 3D reconstructions were made. On those reconstructions defects could be spotted (fig. 4). The validations of the defects were done both on C and B scans (fig. 5).

On the MicroCT investigations performed in the normal conditions the interfaces were well characterize proving the results obtained from the OCT and confocal investigations (fig. 6).

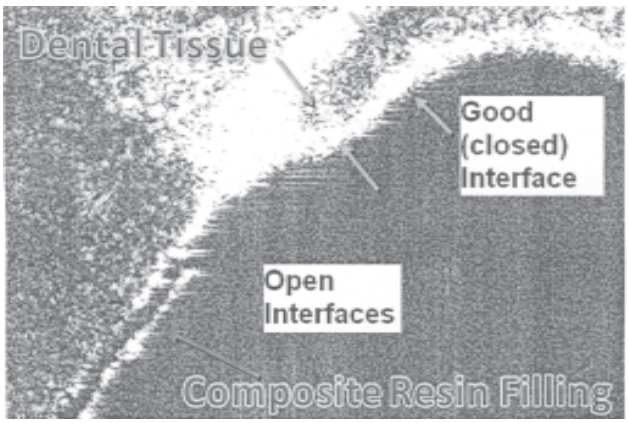

Fig. 2. OCT investigation in Time Domain manner at 1300 nm and C scan procedure. The good interface between the resin filling and the dental tissue is represented by green arrows. The open interface is represented y red arrows

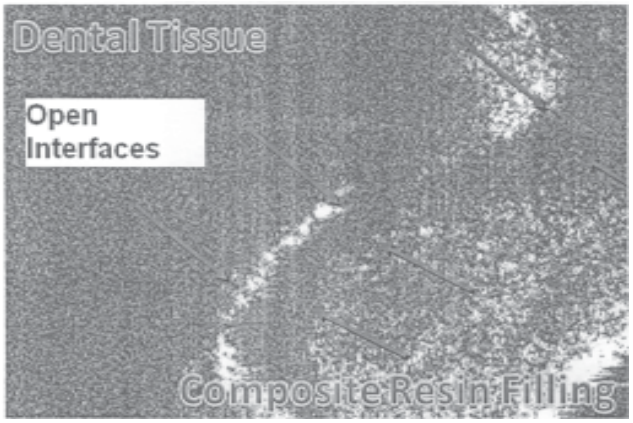

Fig. 3. OCT investigation in Time Domain manner at 1300 nm and C scan procedure. Open interface between the resin filling composite and the dental tissues.

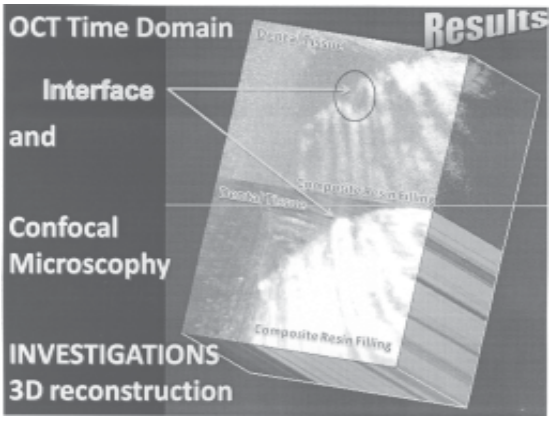

Fig. 4. 3D reconstruction of the resin composite dental structure interface achieved from OCT investigation in Time Domain mode, at 1300 nm, C scan. A defect at the interface could be spotted at the tip of the arrow on the OCT investigation.

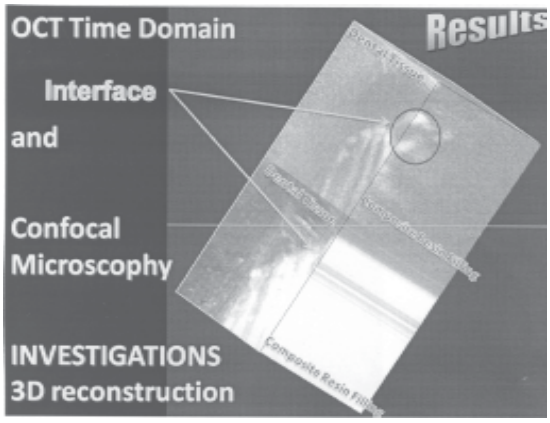

Fig. 5. 3D reconstruction of the resin composite dental structure interface achieved from OCT investigation in Time Domain mode, at 1300 nm, B scan. The existence of the defect was validated by another OCT investigation in the B scan mode.

Conclusions

In conclusion, noninvasive evaluations methods have great capability to accomplish a high quality characterization of the class II direct composite restorations. Especially OCT working in Time Domain mode has a great capability to evaluate the interfaces when 3D reconstructions are performed.

Acknowledgement: This paper was supported by the project "Development and support for multidisciplinary postdoctoral programs in primordial technical areas of the national strategy for research – development – innovation" 4D-POSTDOC, contract nr. POSDRU/89/1.5/S/52603, project co-funded from the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013.

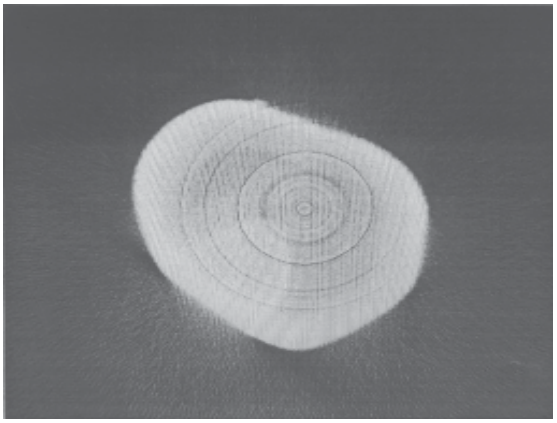

Fig. . 6. Micro CT validations

References

1. WILSON EG, MANDRADJIEFF M, BRINDOCK T. Controversies in posterior composite resin restorations. Dent Clin North Am. 1990; 34:27-44.
2. DENISE ARLIANE AMARANTE DE CAMARGO, MÁRIO ALEXANDRE COELHO SINHORETI, LOURENÇO CORRER-SOBRINHO, MANOEL DAMIÃO DE SOUSA NETO,SIMONIDES CONSANI: Influence of the methodology and evaluation criteria on determining microleakage in dentin–restorative interfaces, Clin Oral Invest. 2006; 10:317–323.
3. COSMIN SINESCU, MEDA LAVINIA NEGRUTIU, CARMEN TODEA, COSMIN BALABUC, LAURA FILIP, AND ROXANA ROMINU, ADRIAN BRADU, MICHAEL HUGHES, ADRIAN GH. PODOLEANU, Quality assessment of dental treatments using enface optical coherence tomography, J. Biomed. Opt., Vol. 13, 2008; 054 - 065
4. M. ROMINU, C. SINESCU, A. GH. PODOLEANU, Optical Coherence Tomography Combined with the Confocal Microscopy Method and Fluorescence for Class V Cavities Investigations, International Journal of Biological and Life Sciences, 2010, 45 -49.
5. MIHAI ROMINU, COSMIN SINESCU, EMANUELA PETRESCU, CLAUDIU HAIDUC, ROXANA ROMINU, MARIUS ENESCU, MICHAEL HUGHES, ADRIAN BRADU, GEORGE DOBRE, ADRIAN G. PODOLEANU, "Optical coherence tomography combined with confocal microscopy for investigation of interfaces in class V cavities", Proc. SPIE 7372, 737228 (2009); doi:10.1117/12.831803
6. MIHAI ROMINU, COSMIN SINESCU, MEDA L. NEGRUTIU, ROXANA O. ROMINU, DANIELA M. POP, FLORIN TOPALA, ADELINA STOIA, EMANUELA PETRESCU, ADRIAN BRADU, GEORGE DOBRE, ADRIAN G. PODOLEANU, Adhesive improvement in optical coherence tomography combined with confocal microscopy for class V cavities investigations Proc. SPIE 7626, 76260Y 2010; doi:10.1117/12.844538

Manuscript received: 6.07.2011