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En-Face Optical Coherence Tomography Combined with Fluorescence in Material Defects Investigations for Ceramic Fixed Partial Dentures

C. Sinescu, M. Negrutiu, M. Romînu, C. Haiduc, E. Petrescu, M. Leretter, and A.G. Podoleanu

Abstract**—**Optical Coherence Tomography (OCT) combined with the Confocal Microscopy, as a noninvasive method, permits the determinations of materials defects in the ceramic layers depth. For this study 256 anterior and posterior metal and integral ceramic fixed partial dentures were used, made with Empress (Ivoclar), Wollceram and CAD/CAM (Wieland) technology. For each investigate area 350 slices were obtain and a 3D reconstruction was perform from each stuck. The Optical Coherent Tomography, as a noninvasive method, can be used as a control technique in integral ceramic technology, before placing those fixed partial dentures in the oral cavity. The purpose of this study is to evaluate the capability of En face Optical Coherence Tomography (OCT) combined with a fluorescent method in detection and analysis of possible material defects in metal-ceramic and integral ceramic fixed partial dentures. As a conclusion, it is important to have a non invasive method to investigate fixed partial prostheses before their insertion in the oral cavity in order to satisfy the high stress requirements and the esthetic function.

Keywords**—**Ceramic Fixed Partial Dentures, Material Defects, En face Optical Coherence Tomography, Fluorescence.

I. Introduction

METAL-CERAMIC fixed partial dentures are considered a standard treatment modality in dental practice. Therefore, their survival rate should be used as criterion for new all-ceramic systems.

Cosmin Sinescu is with the University of Medicine and Pharmacy Victor Babes from Timisoara, Romania, Faculty of Dentistry, Dental Materials and Dental Technologies Department (phone: +40722280132; e-mail: minosinescu@yahoo.com).

Meda Negrutiu. is with the University of Medicine and Pharmacy Victor Babes from Timisoara, Romania, Faculty of Dentistry, Dental Materials and Dental Technologies Department (e-mail: meda_negrutiu@yahoo.com).

Mihai Romînu is with the University of Medicine and Pharmacy Victor Babes from Timisoara, Romania, Faculty of Dentistry, Dental Materials and Dental Technologies Department (e-mail: mrominu@hotmail.com).

Claudiu Haiduc is with the University of Medicine and Pharmacy Victor Babes from Timisoara, Romania, Faculty of Dentistry, Dental Prosthodontic Department (phone: +40722280132; e-mail: minosinescu@yahoo.com).

Emanuela Petrescu is with the University of Medicine and Pharmacy Victor Babes from Timisoara, Romania, Faculty of Dentistry, Dental Prosthodontic Department (phone: +40722280132; e-mail: minosinescu@yahoo.com).

Marius Leretter is with the University of Medicine and Pharmacy Victor Babes from Timisoara, Romania, Faculty of Dentistry, Dental Prosthodontic Department (phone: +40722280132; e-mail: minosinescu@yahoo.com).

Adrian Gh. Podoleanu is with the Applied Optics Group, University of Kent, Canterbury, UK (e-mail: A.G.H.Podoleanu@kent.ac.uk).

Noninvasive research methods are very useful in characterizing the infrastructure of the fixed partial brides, due to the possibility of using the support after the evaluation in order to make a good and much more resistant dental bridge.

The purpose of this study is to analyze the existence of possible fractures in several metal ceramic and integral ceramic fixed partial dentures using Optical Coherence Tomography as a non invasive method combined with a fluorescent method.

II. Materials and Methods

Two *en-face* OCT systems have been used. Both use similar pigtailed super-luminescent diodes (SLD) emitting at 1300 nm and having spectral bandwidths of 65 nm which determine an OCT longitudinal resolution of around 17.3 microns in tissue. The first OCT system performs OCT only, in both C-scan and B-scan regimes, with low NA, allowing 1 cm lateral image size. The second system, equipped with a confocal channel at 970 nm, uses a high NA interface optics allowing 1 mm image size. The configuration of the second system, as shown in Fig. 2, uses two single mode directional couplers. Light from the SLD source is injected into the system via the directional coupler DC1 which splits the light towards the two arms of the interferometer, the probing and the reference arm respectively. The probing beam is reflected by the dichroic beam-splitter BS1 and then sent via the galvanometer scanners SX and SY to the sample. Two telescopes incorporated between these elements conveniently alter the diameter of the beam in order to match the aperture of different elements in the probing path and convey a probing beam of around 8 mm in diameter through the microscope objective MO's pupil plane. Hence, a lateral resolution of around 2 μm in the confocal channel could be achieved. A transversal resolution better than 5 microns is obtained in the OCT channel. Light back-scattered by the sample passes a second time through the object arm and is guided towards the single mode directional coupler DC2 via DC1 where it interferes with that coming from the reference arm. Both output fibers from DC2 are connected to two pin photo-detectors in a balanced photo-detection unit. A computer driven translation stage (TS) is used to construct B-scan images by stopping the frame scanner and moving TS along the optical axis of the reference beam [3, 8]. The scanning procedure is similar to that used in any confocal microscope, where the fast scanning is *en-fa*ce (line rate) and the depth scanning is much slower (at the frame rate). The *en-face* scans provide an instant comparison to the familiar sight provided by direct view or by a conventional microscope. Features seen with the naked eye can easily be compared with features hidden in depth. Sequential and rapid switching between the *en-face* regime and the cross-section regime, specific for the *en-face* OCT systems, represents a significant advantage in the non-invasive imaging as images with different orientations can be obtained using the same system [7, 8].

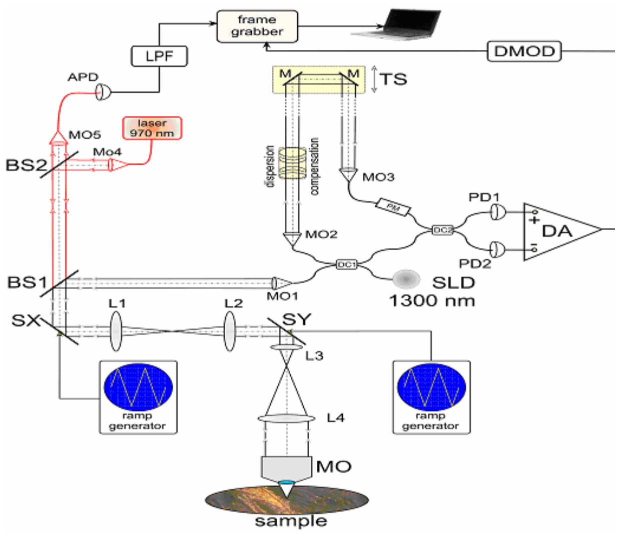


Fig. 1 En-face OCT at 1300 nm/confocal at 970 nm system. SLD = superluminescent diode, SX, SY: X and Y scanners; IMG = index matching gel; APD: avalanche photodiode; L1, L2, L3, L4: lenses: MO1-5: microscope objectives; PD1, 2: pin photodetectors; BS1,2: beamsplitters; LPF: low pass filter; PM: polarization

As shown in Fig. 2, in the *en-face* regime, the frame grabber is controlled by signals from the generators driving the X-scanner and the Y-scanner. One galvo-scanner is driven with a ramp at 500 Hz and the other galvo-scanner with a ramp at 2 Hz. In this way, an *en-face* image, in the plane (x, y) is generated at constant depth. The next *en-face* image at a new depth is then generated by moving the translation stage in the reference arm of the interferometer and repeating the (x, y) scan. Ideally, the depth interval between successive frames should be much smaller than the system resolution in depth and the depth change applied only after the entire *en-face* image has been collected. However, in practice, to speed up the acquisition, the translation stage was moved continuously. Alternatively, a scanning delay line could be used, which can achieve faster depth scanning rates. In the images presented below, no other phase modulation was employed apart from that introduced by the X-galvanometer scanner. We demonstrated in a previous study the role played by the image size in balancing the effects of an external phase modulator and of the modulation produced by the transversal scanner. If the image is sufficient large, then the distortions introduced by not using a phase modulator are insignificant. The other system contains an OCT channel only, and the X and Y scanners are grouped spatially. Only one lens L of focal length 4 cm is used between the XY scanner head, allowing a larger lateral size image and a coarser transversal resolution in comparison with the second system, of only 15 microns. The X and Y scanners are similar and driven at the same line rate (500 Hz) and frame rate (2 Hz) as in the previous system. In the cross-section regime, the frame grabber is controlled by signals from the generator driving the X-scanner (or the Y-scanner) with a ramp at 500 Hz and the translation stage moving over the depth range required in 0.5 s. In this case, an OCT cross-section image is produced either in the plane (x, z) or (y, z) [3, 7, 8].

Metal Ceramics Fixed Partial Dentures

256 metal ceramics and integral ceramic fixed partial dentures was investigated using En face Optical Coherence Tomography as a non invasive method combined with a fluorescent method. 350 slices were used for each set of investigation. The distance between the slices was 10 microns. A 3D reconstruction was made for each investigation in order to evaluate the position and the magnitude of the ceramic defect.

III. En Face OCT Results

After the investigation with only the En Face OCT method the material defects reveals from the ceramic materials. For the big defects the results were hard to evaluate because of the details and the magnitude of the defects. The small defects were imaged very good and all of them could be used into biomechanical noninvasive evaluation methods such as numerical simulation in order to asses the possibility of the ceramic fracture.

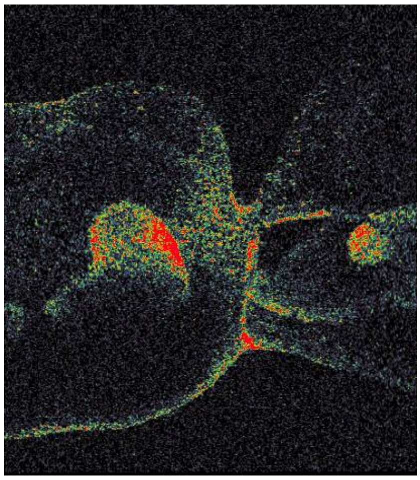


Fig. 2 Defect inside the ceramic material revealed with en-face OCT method

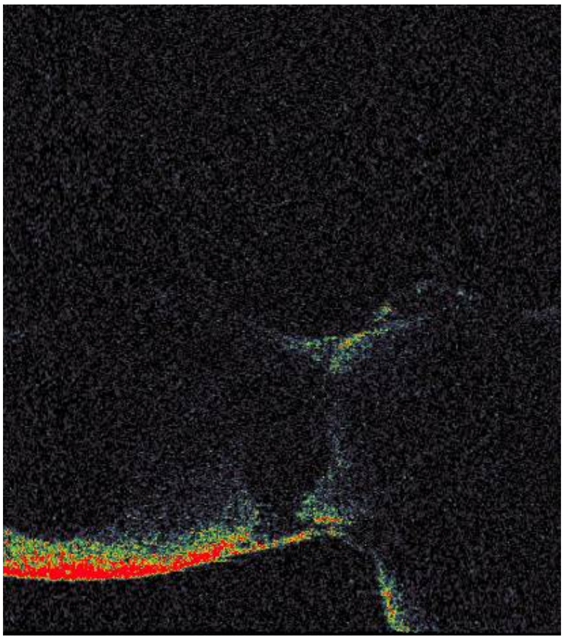


Fig. 3 The same ceramic defect hard to evaluate because of the thickness of the ceramic material

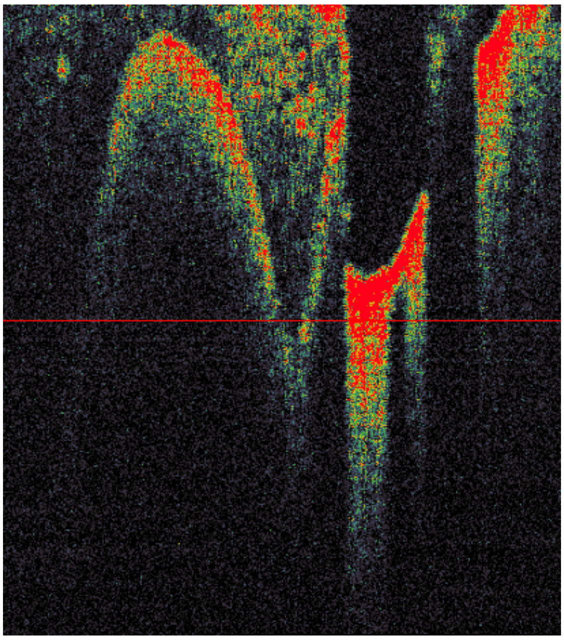


Fig. 4 B-scan of the same ceramic fixed partial denture sample in order to prove the presence of the material defect inside the ceramic core

Despite the capability of the en face OCT noninvasive method to reveal the imbedded ceramic defects the fluorescent method can help in order to increase the contour of the defect.

IV. PSOCT Results

PSOCT images from different metal-ceramic fixed partial prostheses are shown below. Using incisal scanning we found many pores which can cause possible fractures of the investigated dental bridges due to its dimensions and its positions. All the pores depicted below are deep in the dental ceramic material; therefore it will be hard to be detected via normal visual inspection. The material defects within the ceramic layers for metal-ceramic prostheses. The detected defects have a large volume highly capable to generate fracture lines in the proximal or almost superficial on the occlusal area, leading to the failure of the prosthetic treatment. The detection of these defects before inserting the prostheses allows all the corrections in order to avoid the fracture of the ceramic component. For a better understanding of the ceramic defect spreading a three dimensional reconstruction can be develop.

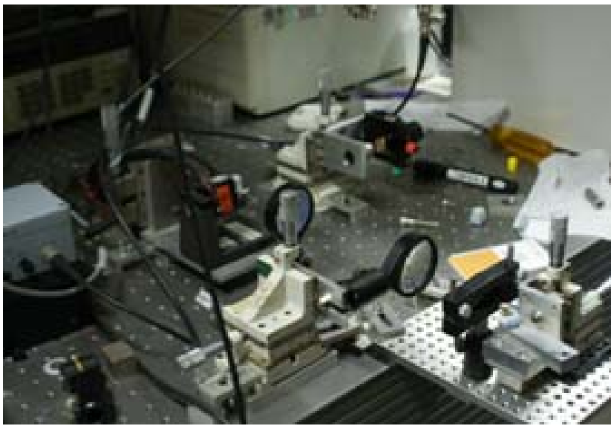
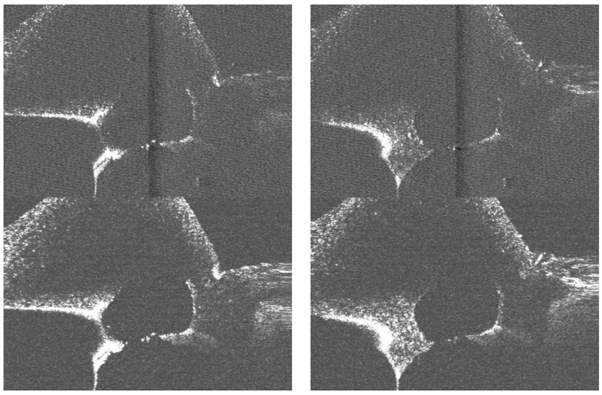


Fig. 5 A part of the PSOCT system architecture



(a) (b)

Fig. 6 Metal Ceramic Fixed Partial Denture Sample 29 investigated with PSOCT: a. slice 28 from 118 and b. slice 37 from 118. Notice the big ceramic defect in the centre of the image

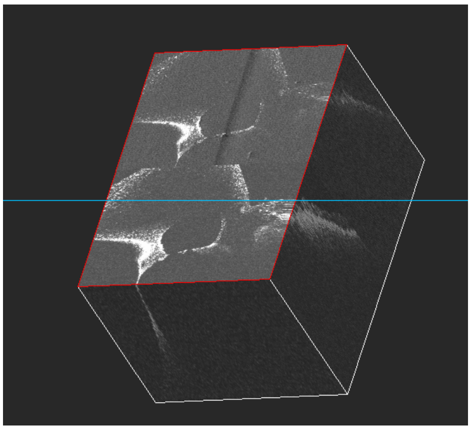


Fig. 7 3D reconstruction of the ceramic defect situated in depth of the metal ceramic fixed partial denture sample nr. 29

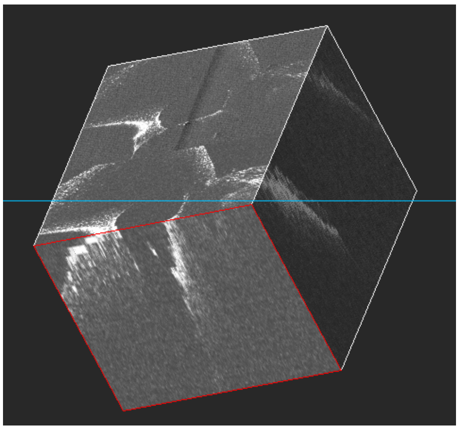


Fig. 8 Detail of the ceramic defect in the 3D reconstruction for sample 29. Note the magnitude of the defect inside the ceramic layers

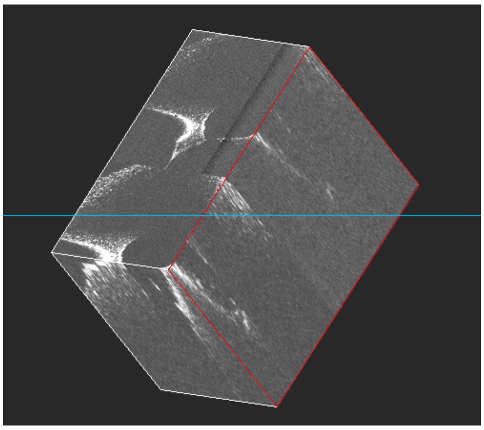


Fig. 9 Detail of the ceramic defect in the 3D reconstruction for sample 29. Note the magnitude of the defect inside the ceramic layers

V. Optical Coherence Tomography Combined with Fluorescence Results

After the fluorescent agent was apply on the ceramic fixed partial dentures the results were received in frames with the same information about the whole material defects inside the prosthetic constructions.

Fig. 10 The fluorescent agent used in the study

Fig. 11 Applying the fluorescent agent using a siringe

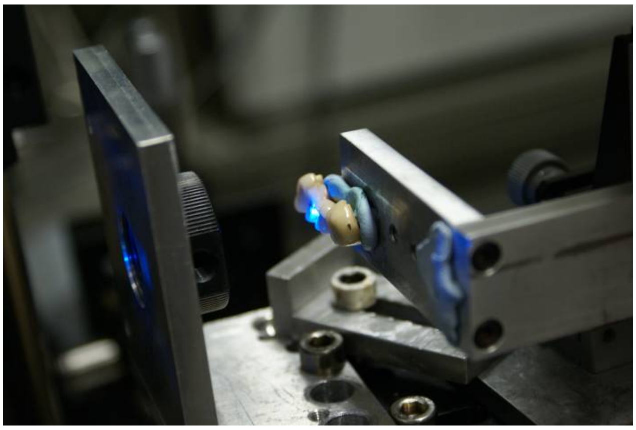


Fig. 12 One of the ceramic fixed partial denture sample in front of the scanning head of the OCT

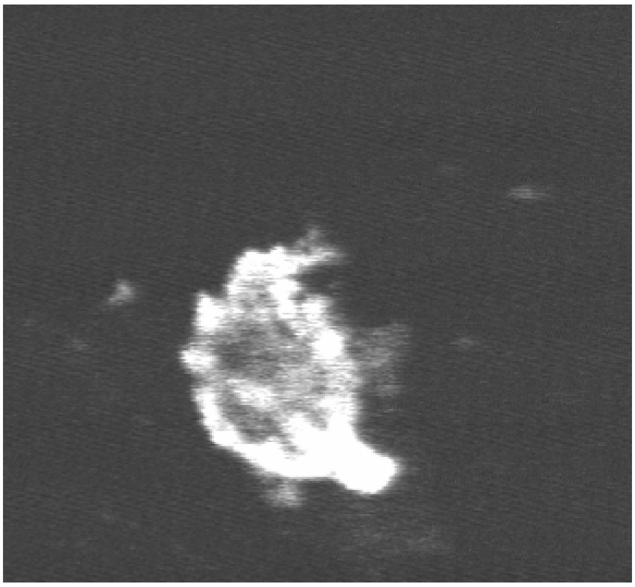


Fig. 13 Image resulted after the OCT combined with fluorescence investigation on ceramic fixed partial denture sample nr. 45. A big defect can be spotted in the middle of the image

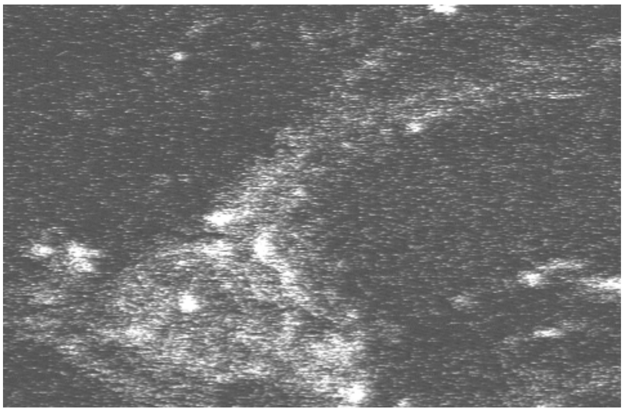


Fig. 14 Material defects inside the ceramic fixed partial dentures sample nr. 102. The image resulted after en face OCT investigation combined with fluorescence

VI. Discussion

Despite the big advantage of the en face OCT non invasive method evaluation of the ceramic fixed partial dentures the bid material defects are hard to imagine because of the thickness of the ceramic layers. Because those defects are the main zone of possible fracture line in the masticatory field, the detail evaluation of the ceramic defects are mandatory. There are several factors that are associated with the stress state created in ceramic restorations, including: thickness of ceramic layers, mechanical properties of the materials, elastic modulus of the supporting substrate material, direction, magnitude and frequency of applied load, size and location of occlusal contact areas, residual stresses induced by processing or pores, restoration-cement interfacial defects and environmental defects.

VII. Conclusion

The detection of ceramic defects before oral inserting the prostheses allows all the corrections in order to avoid the fracture of the ceramic component. The fractures that occur within the structure of these prostheses were motivated by the elasticity module of the ceramics and by the defects within the ceramic layers. Early detection of substance defects within these layers allows for optimal corrections before inserting them and applying masticatory stress together with reduction of fractures. For the big material defects a good evaluation can be done by a fluorescent agent. For the imbedded ceramic defects the en face OCT noninvasive method of evaluation remains the only method capable to evaluate the prognostic of a prosthetic construct.

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