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En-Face Optical Coherence Tomography and Fluorescence in Evaluation of Orthodontic Interfaces

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***Abstract*—**Bonding has become a routine procedure in several dental specialties – from prosthodontics to conservative dentistry and even orthodontics. In many of these fields it is important to be able to investigate the bonded interfaces to assess their quality. All currently employed investigative methods are invasive, meaning that samples are destroyed in the testing procedure and cannot be used again. We have investigated the interface between human enamel and bonded ceramic brackets non-invasively, introducing a combination of new investigative methods – optical coherence tomography (OCT), fluorescence OCT and confocal microscopy (CM). Brackets were conventionally bonded on conditioned buccal surfaces of teeth. The bonding was assessed using these methods. Three dimensional reconstructions of the detected material defects were developed using manual and semi-automatic segmentation. The results clearly prove that OCT, fluorescence OCT and CM are useful in orthodontic bonding investigations.

***Keywords*—**Optical coherence tomography, Confocal Microscopy, Orthodontic Bonding.

I. Introduction

IN order to assess the quality and success of the treatment, it is necessary to investigate the ceramic bracket - enamel interfaces. Several possible methods are cited in literature, including dye penetration and thermo cycling and mechanical testing followed by microscopic evaluation [10, 11, 12]. However, all of these methods suffer from the major disadvantage that the tested samples cannot be used after the evaluation, even if proved flawless. An alternative technique is laser micro spectral analysis. First introduced in 1962 as a method of investigating the surfaces of metals, the technique has found new applications in more recent times, where it is often known as spectroscopy by laser induced plasma. A key feature of this technology is that it needs only a small quantity of the material, around 0.1g. The laser micro spectral analysis device consists of an infrared pulsed laser, usually with ruby or neodymium doped glass as the active medium. By allowing for an assessment of chemical composition of the interface area, laser micro spectral analysis can be used to establish the presence of micro leakage in the ceramic bracket enamel interfaces. It is possible to make either a semiquantitative or a quantitative analysis. However, as it requires puncturing of the sample, it is clearly an invasive procedure.

A further method for interface investigation employs Secondary Ion Mass Spectrometry (SIMS) and Sputtered Neutral Mass Spectrometry (SNMS) to obtain information on minor and major element composition. Both SIMS and SNMS methods use a focused, mono-energetic, chemically pure ion beam of typically 1-10 keV to sputter erode the surface under analysis. A small fraction of the sputtered material becomes ionized due to the sputtering process itself and, in SIMS, it is these ions that provide the high-sensitivity information for which the technique is known. Being a mass spectrometry technique, it can detect all elements and isotopes and, in favorable conditions, the detection limit can be in the low ppb region. As SIMS simultaneously sputters, erodes and detects the ion signal, it is an ideal technique to rapidly produce depth profiles of species of interest.

The aim of our study was to evaluate the interface between ceramic orthodontic brackets and human enamel from a new perspective, using a combination of non-invasive methods – OCT and CM. The great advantage of these methods is that samples stay intact during and after examination.

II. Materials and Methods

235 non-carious and crack-free extracted human teeth were collected and stored in tap water at 4-6ºC until processing. All teeth were professionally cleaned with pumice and rotary brushes. In order to maintain a constant quality, the brushes were changed after every 5th tooth. After cleaning, the buccal surfaces were etched with 38% ortho-phosphoric acid for 30" then thoroughly rinsed with water spray and carefully and completely dried with air spray. A bonding agent was

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subsequently applied with a brush to the etched buccal surfaces and to the base of each bracket, and thinned with a gentle stream of air. Self-curing composite resin was placed on the bracket base and the bracket was firmly pressed onto the conditioned enamel surface. Excess composite was removed with a probe. The teeth were then probed using the dual channel system, OCT/CM. An en-face OCT system operating as 1300nm and as described in previous reports [1, 2] was employed. The optical configuration [4] uses two single mode directional couplers with a superluminescent diode as the source. To obtain 3D information about the object, the system is equipped with three scanning means, one to scan the object in depth and two others to scan the object transversally. Depending on the order these scanners are operated and on the scanning direction associated with the line displayed in the raster of the final image delivered, different possibilities exist. Our system can deliver A, B, T and C-scan (en-face) OCT images. To construct B-scan images, no signal is applied to the frame scanner, the line scanner is driven with the same signal as in the C-scanning regime and TS is moved along the optical axis of the reference beam. In this case, the frame grabber is controlled by signals from the generator driving the SX-scanner (or the SY-scanner) with a ramp at 500 Hz and the translation stage TS is moving over the required depth range in 0.5 s. In this case, an OCT cross-section image is produced either in the plane (x, z) or (y, z). In the images presented below, no other phase modulation was employed apart from that introduced by the galvanometer scanner, determining the line in the raster. 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 system operates together with a confocal microscope at a wavelength of 970 nm. This allows for the easy identification of the area of interest which can then be scanned using the OCT. Confocal microscopy can detect superficial defects itself, whereas the OCT is required to identify the deeper material defects. For each sample there was an OCT investigation, a combine OCT / Confocal investigation and OCT / Confocal / Fluorescence investigation after the fluorescence agent was added to the sample (Fig. 1).

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 microm 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-fac*e (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].

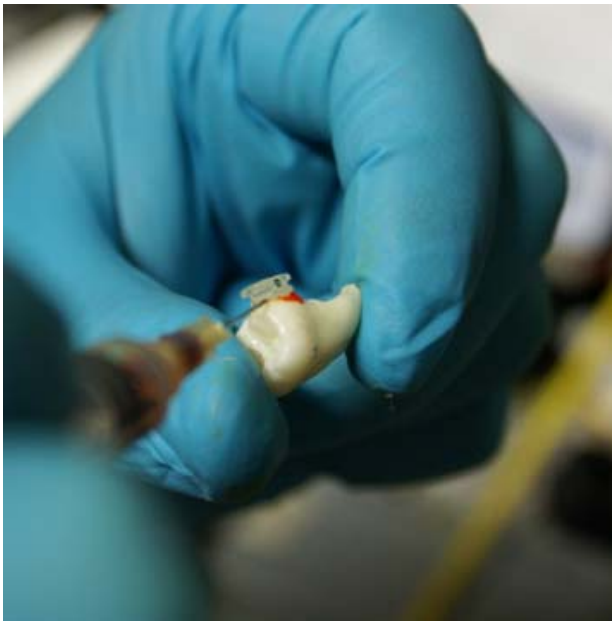

Fig. 1 The fluorescence agent is added to the sample.

III. Results

All samples were investigated using the above methods. Defects were found in 33 samples. These material defects were found inside the matrix resin, between the bracket and enamel, represented by chains of small gaps. Other materials defects were found outside the bracket resin enamel interface.

These materials defects were larger than the ones trapped in the matrix between the bracket and enamel. Using the confocal system in conjunction with the OCT allowed us to observe that some of the material defects in the chains communicate with others. These results were compared with the fluorescence OCT investigations (Fig. 2).

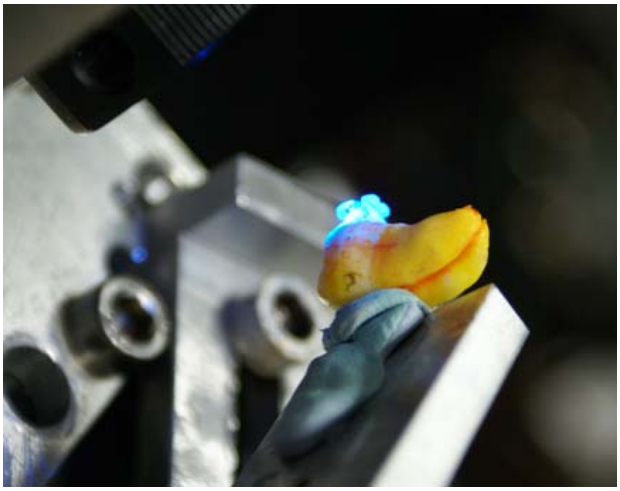

Fig. 2 OCT investigation of the samples using Fluorescence

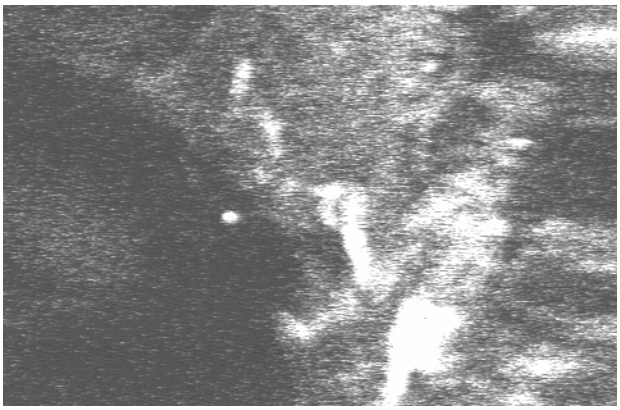

Fig. 3 Materials defects in the orthodontic interface (sample 34)

IV. Conclusion

Optical coherence tomography clearly proves its utility in investigating orthodontic bonding. With this non-invasive method the material defects trapped inside the matrix resin can be localized and 3D reconstructed. Adding confocal microscopy to the OCT investigation leads to a much better evaluation of the communications of these gaps in order to forecast the strength of the orthodontic brackets' bonding. This allows us to perform numerical simulation of the brackets resin enamel interfaces. Further studies are necessary in order to establish a correlation between clinical acceptability of the bracket-tooth interface and gap size. An association between OCT investigation and subsequent mechanical testing would probably be a suitable choice in order to determine the minimum gap acceptable in clinical applications. Finally the Fluorescence OCT point out the micro leakage for the samples investigated.

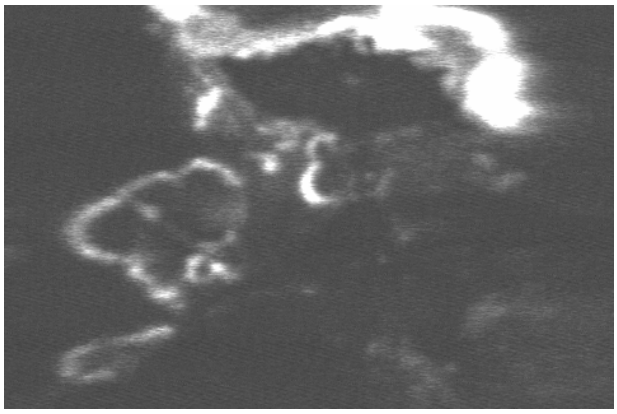

Fig. 4 Materials defects in the orthodontic interface (sample 58)

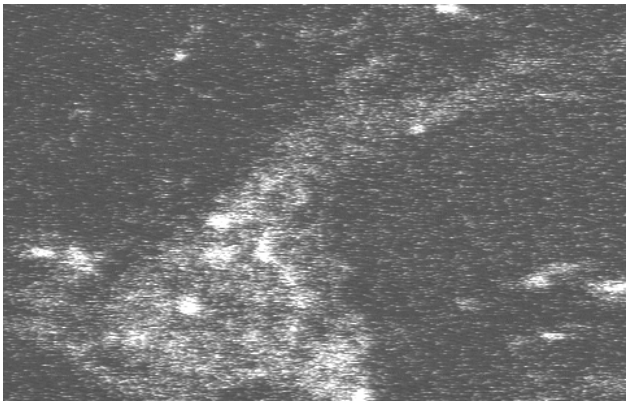

Fig. 5 Materials defects in the orthodontic interface (sample 147)

References

[1] B. T. Amaechi, A. Gh. Podoleanu, S.M. Higham, D. Jackson, "Correlation of Quantitative Light Induced Fluorescence and Optical Coherence Tomography Applied for Detection and Quantification of Early Dental Caries", Journal Biomedical Optics (2003).

[2] B. T. Amaechi, A.Gh.Podoleanu, G. Komarov, J. Rogers, S. Higham, D. Jackson "Application of Optical Coherence Tomography for Imaging and Assessment of Early Dental Caries Lesions", Laser Physics, Special Issue No.2, Laser Methods in Medicine and Biology, Vol.13, No.5 703-710, May , (2003).

[3] D. Huang, E.A. Swanson, C.P. Lin, J.S. Schuman et al., "Optical Coherence Tomography", Science 1991 254:1178-1181, (2000).

[4] A. Gh. Podoleanu, J.A. Rogers, D.A.Jackson, S. Dunne, "Three Dimensional Images from retina and skin". Opt.Express, Vol.7, No.9, p.292-298.

[5] BR. Masters, "Three-dimensional confocal microscopy of the human optic nerve in vivo," Opt. Express, 3, 356-359 (1998), http://epubs.osa.org/oearchive/source/6295.htm;

[6] J.A. Izatt, M.R. Hee, G.M. Owen, E.A. Swanson and J.G. Fujimoto, "Optical coherence microscopy in scattering media," Opt. Lett. 19, 590-593 (1994);

[7] C.C. Rosa, J. Rogers and A.Gh. Podoleanu, "Fast scanning transmissive delay line for optical coherence tomography," Opt. Lett. 30, 3263-3265 (2005);

[8] A.Gh. Podoleanu, G.M. Dobre, D.J. Webb and D.A.Jackson, "Coherence imaging by use of a Newton rings sampling function", Optics Letters, 21(21), 1789 (1996);

[9] A.Gh. Podoleanu, M. Seeger, G.M. Dobre, D.J. Webb, D.A. Jackson, F. Fitzke, "Transversal and longitudinal images from the retina of the living eye using low coherence reflectometry," Journal of Biomedical Optics, 3, 12 (1998).
[10] H. Türkkahraman and H. Cenker Küçükeşmen, "Porcelain surface-conditioning techniques and the shear bond strength of ceramic brackets" The European Journal of Orthodontics 28(5):440-443, (2006).
[11] P. Surmont, L. Dermaut, L. Martens, M. Moors "Comparison in shear bond strength of orthodontic brackets between five bonding systems related to different etching times: an in vitro study" Am. J Orthod Dentofacial Orthop. 101: 414–419, (1992).
[12] J. Artun, S Bergland, "Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment" Am J Orthod., 85:333-40, (1984).
[13] B. R. Masters, "Three-dimensional confocal microscopy of the human optic nerve in vivo," Opt. Express, 3, 356-359 (1998).