Optical Coherence Tomography and Micro Computer Tomography Investigations on Pressed Ceramic Veneers

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Abstract— The ceramic veneers are often use in order to increase the esthetic aspect of the frontal teeth when discolorations or old fillings are involved. But some of those ceramic veneers are fractured in a short period of time after they were bonded into the oral cavity. The aim of this study was to analyze the integrity of the ceramic veneers using a noninvasive method like the optical coherence tomography working in Time Domain. The obtained results were validated by Micro Computer Tomography. The conclusions point out the importance of investigation the integrity of every veneer before bonding in into the oral cavity.

Keywords— Ceramic Veneers, Optical Coherence Tomography, Micro Computer Tomography

I. Introduction

Cosmetic dentists have been using porcelain veneers for smile makeovers for more than 30 years. While the prognosis of porcelain veneers was uncertain at the beginning, abundant dental literature can be found that reports about the clinical longevity of porcelain veneers.

Porcelain veneers have become the most used component at offices that focus on cosmetic dentistry. Many times patients wonder whether they want to take the risk of having their teeth prepared to receive beautiful porcelain veneers. While these concerns are understandable, tooth reduction is necessary to create anatomically correct teeth. For the same reason, so-called lumineers are rarely applicable. Lumineers are placed on unprepared a tooth that causes them to be over contoured and too bulky. In addition, they do not permit the integration in the dental arch.

This may be required when correcting severely misaligned teeth or when prior dental restoration is being replaced. However, a skilled cosmetic dentist knows how to provide an optimum preparation for any situation. In addition, an experienced cosmetic dentist understands the chemistry of his products and knows how to work with them to obtain optimum bonding results and superior longevity of porcelain veneers. The study of Kihn PW and colab reported that all veneers evaluated after 48 month were still clinically acceptable [1].

The objective of Guess PC and colab. studies was midterm evaluation of a prospective five years clinical study on long term performance and success rate of pressed-ceramic veneers with two extended preparation design. Anterior teeth of 25 patients were restored with 66 extended veneers. Forty-two overlap veneers (incisal edge reduction 0,5 – 1,5 mm, butt-joint) and 24 full veneers were inserted. Both veneer design were similar in buccal (0,5 mm) and proximal (0,5 – 0,7 mm) chamfer preparation, but differed in palatal extension. Ceramic veneers were fabricated with IPS Empress and adhesively luted with dual polymerizing composite Variolink II (Ivoclar Vivadent). Clinical reevaluation was performed 6, 12, 25, 39, 45 and 62 months after insertion of the veneers according to the modified USPHS criteria. Absolute failures were recorded as survival rate, relative failures demonstrated by Kaplan-Meier success rate [2]. After an observation time up to 5 years, survival rate of full veneers was 100%, of overlap veneers 97,5% due to one severe fracture. Kaplan-Meier analysis of the relative failures in a success rate of 85% for full veneers and 72% for overlap veneers. Reasons for relative failures were cracks, ceramic-cohesive-fractures, and loss of adhesion. No significant differences were found between the two veneer groups. Secondary caries and endodontic complications did not occur. Increased clinical service time resulted in enhanced marginal discoloration and decrease of marginal adaptation. Extended pressed-ceramic veneers proved to be reliable procedures to restore larger deficits in anterior teeth. Pronounced palatal extension of full veneers was not linked to a higher failure probability. Reliable adhesive bonding, as well as ceramic fatigue and resistance are considered key factors for long-term success of extended veneer restorations.

An up to 16 years prospective study of 304 feldspathic porcelain veneers prepared by the same operator in 100 patients was performed by Layton D and colab. [3]. A total of 304 porcelain veneers on incisors, canines and premolars in 100 patients completed by one prosthodontist between 1998 and 2003 were sequentially included. Preparations were designed with chamfer margins, incisal reduction and palatal overlap. At least 80% of each preparation was in enamel. Feldspathic porcelain veneers from refractory dies were etched (hydrofluoric acid), silanated and cemented (Vision 2, Mirage Dental Systems). Outcomes were expressed as percentages (success, survival, unknown, dead, repair, failure). The results were statistically analyzed using the chi-square test and

Kaplan-Meier survival estimation. Statistical significance was set at P < 0, 05. The cumulative survival for veneers was 96% +/- 1% at 5 to 6 years, 93% +/- 2% at 10 to 11 years, 91% +/- 3% at 12 to 13 years and 73% +/- 16% at 15 to 16 years. The marked drop in survival between 13 and 16 years was the result of the death of 1 patient and the low number of veneers in that period. The cumulative survival was greater when different statistical methods were employed. Sixteen veneers were associated with esthetics (31%), mechanical complications (31%), periodontal support (12,5%), loss of retention >2 (12,5%), caries (6%) and tooth fracture (6%). Statistically significantly fewer veneers survived as the time in situ increased.

Feldspathic porcelain veneers, when bonded to enamel substrate, offer a predictable long term restoration with a low failure rate. The statistical methods used to calculate the cumulative survival can markedly affect the apparent outcome and thus should be clearly defined in outcome studies. Marginal adaptation of the ceramic veneers was investigated by Sinescu C and colab [4], [5]. 32 Empress Veneers (Ivoclar Vivadent, Lichtenstein) were investigated using en face Optical Coherence Tomography (OCT). The scanning procedure was performed vestibular, oral, mesial and distal for each sample. All the samples were bonded with the same adhesive cement. Two en-face OCT systems have been used. Both use similar pigtailed superluminescent diodes (SLD) emitting at 1300 nm and having spectral bandwidths of 65 nm which determine an OCT longitudinal resolution of around 17.3 µm in tissue. The first OCT system is a combined OCT/confocal system, which is equipped in addition with a confocal channel at 970 nm and uses a high NA interface optics allowing 1 mm image size. The en face OCT scanning reveals pour marginal adaptation for some ceramic veneers (18 samples). The marginal adaptation problems were identified especially in proximal and oral areas. The lack of the adhesive cement could lead to cavities in the depicted areas. Also the gaps from the veneers and the teeth could initiate debonding. A normal eye inspection or an inspection with the dental instruments could not detect those problems because of the small dimensions of the defects. In times, because of these cavities, a sensitivity of the pulp could occur due to incorrect marginal adaptation of the veneers. For all those reasons a non invasive method like en face Optical Coherence Tomography is necessary to investigate and evaluate the prognostic of the bonded ceramic veneers [7, 8, 9].

II. Problem Formulation

The aims of this study were to evaluate the integrity of the dental ceramic veneers before setting them in the oral cavity in order to depict the defects inside the ceramic layers and to prevent the prosthetic fracture and failure.

III. Problem Solution

54 Empress Veneers (Ivoclar Vivadent, Lichtenstein) were investigated using en face Optical Coherence Tomography (OCT) (Fig.1.). The scanning procedure was performed vestibular, oral, mesial and distal for each sample (Fig.2.). Two en-face OCT systems have been used. Both use similar pigtailed superluminescent 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 is a combined OCT/confocal system, which is equipped in addition with a confocal channel at 970 nm and uses a high NA interface optics allowing 1 mm image size. The configuration of the second system, as shown in Fig. 1, 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 [10, 11]. 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 [12, 13].

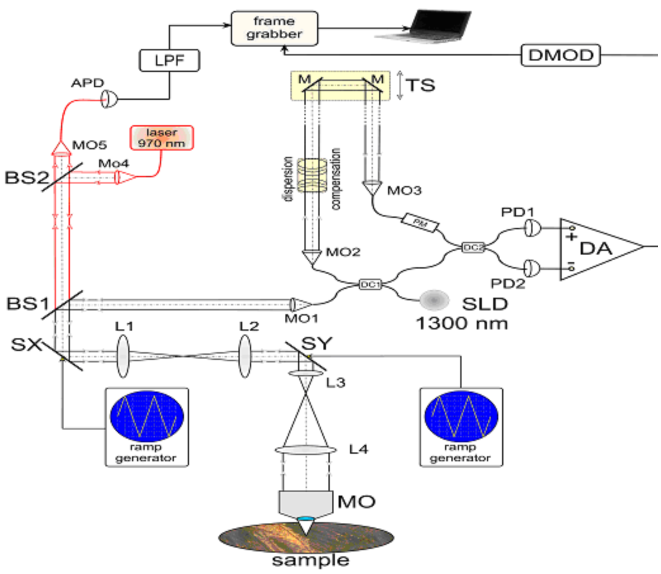

Fig.1. En-face OCT at 1300 nm/confocal at 970 nm system. SLD = superluminescent diode, SX, SY: X and Y scanners; IMG = index matching gel; APD: avalanche photodiode; L1, L2, L3, L4: lenses: MO1-5: microscope objectives; PD1, 2: pin photo detectors; BS1,2: beam splitters; LPF: low pass filter; PM: polarization

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 [14, 15].

Fig. 2. Aspects from the scanning procedure of the ceramic veneers.

For the Micro Computer Tomography (MicroCT), the samples were scanned using cone beam micro-CT [6] (Fig. 3). 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.

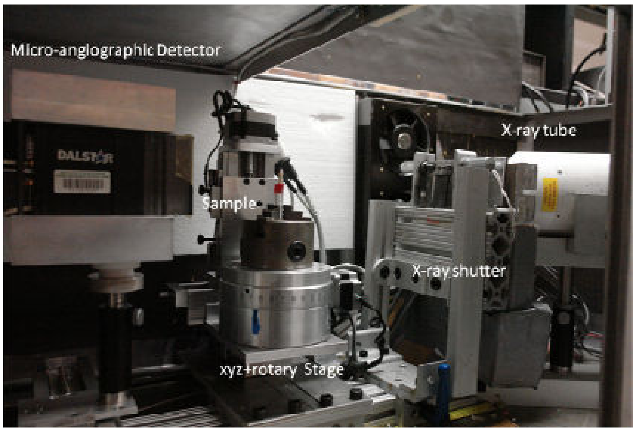

Fig. 3. Aspects of the Cone Beam Micro-CT setup.

IV. Results

The results obtained after the OCT investigation in Time Domain pointed out some defects inside the ceramic layers of the veneers. In order to observe better the defects 3D reconstruction was performed.

All the defects depicted by OCT Time Domain investigations were validate by MicroCT analysis.

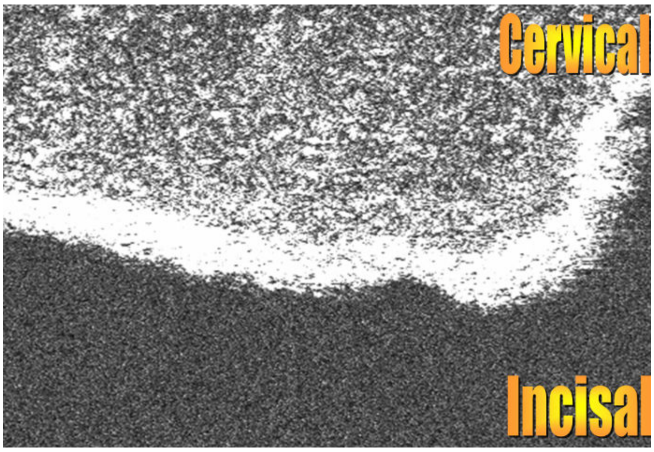

Fig. 4. En Face OCT investigation of ceramic veneer sample nr.3. Slice 20 from 110 stuck images with 18 degree scanning.

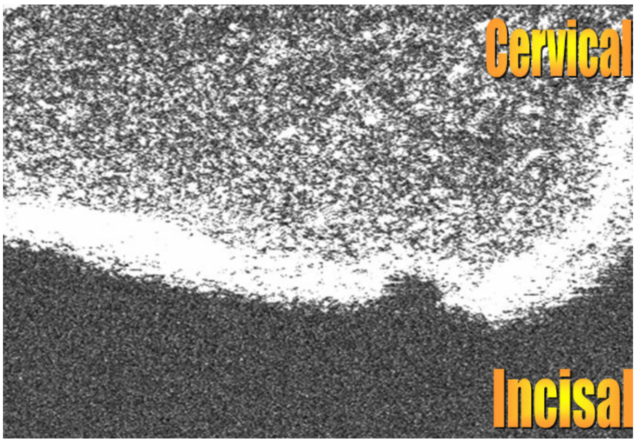

Fig. 5. En Face OCT investigation of ceramic veneer sample nr.3. Slice 22 from 110 stuck images with 18 degree scanning.

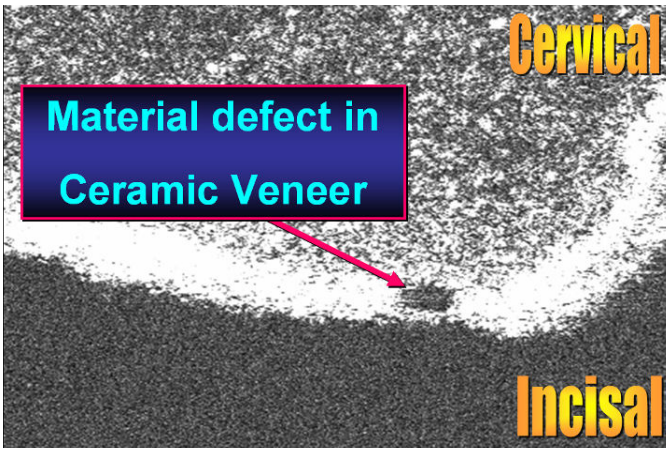

Fig. 6. En Face OCT investigation of ceramic veneer sample nr.3. Slice 23 from 110 stuck images with 18 degree scanning.

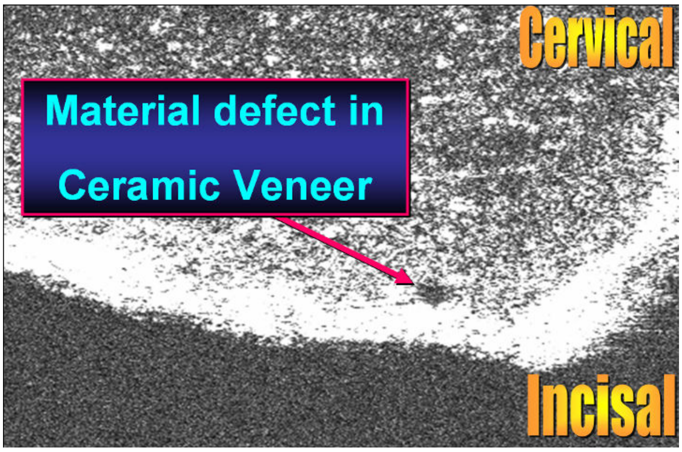

Fig. 7. En Face OCT investigation of ceramic veneer sample nr.3. Slice 26 from 110 stuck images with 18 degree scanning.

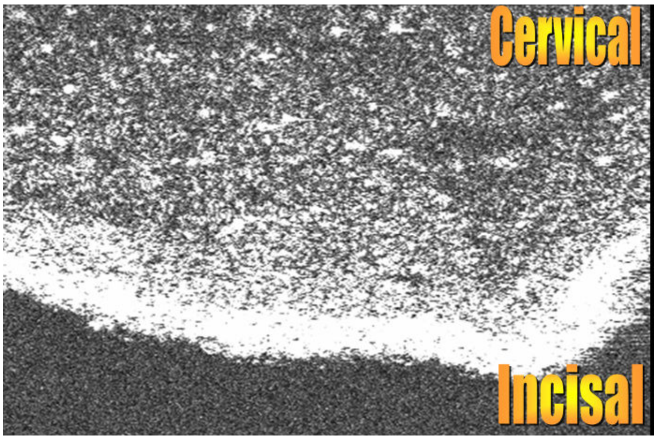

Fig. 8. En Face OCT investigation of ceramic veneer sample nr.3. Slice 29 from 110 stuck images with 18 degree scanning.

For the ceramic veneer sample nr. 3 an en face OCT revealed a round material defect inside the ceramic layers. The forming of the defect could be easily observed in Fig. 4 – 8. For a better understanding of the defect position in the ceramic veneer a three dimensional reconstruction was developed (Fig. 9 – 12). Also the 3D reconstruction works as a validation procedure in order to evaluate the ceramic defect in all three dimensions (Fig. 10 – 12). Figure 4 for the en face investigation and figure 9 for the 3D reconstruction are important to evaluate the ceramic material without defects inside. The presence of the material defects in the incisal areas as in sample 3 could lead easily to the fracture of the ceramic veneers.

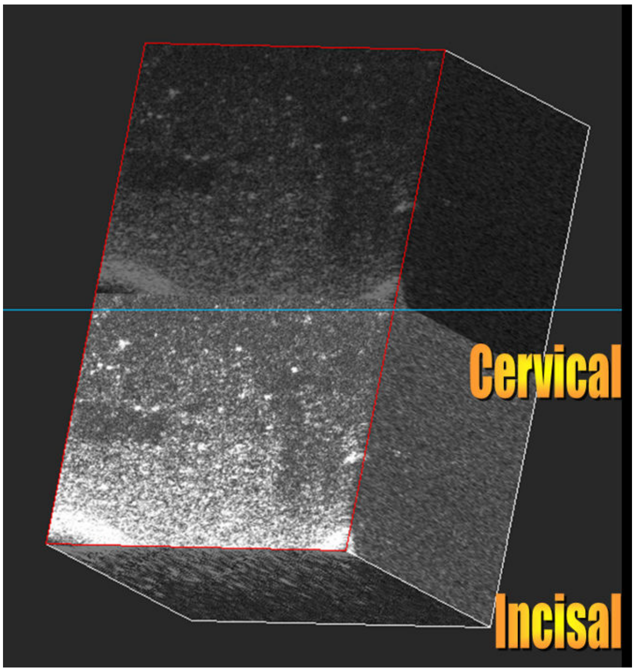

Fig. 9. En Face OCT investigation of ceramic veneer sample nr.3. 3D reconstructions of the 110 stuck images with 18 degree scanning.

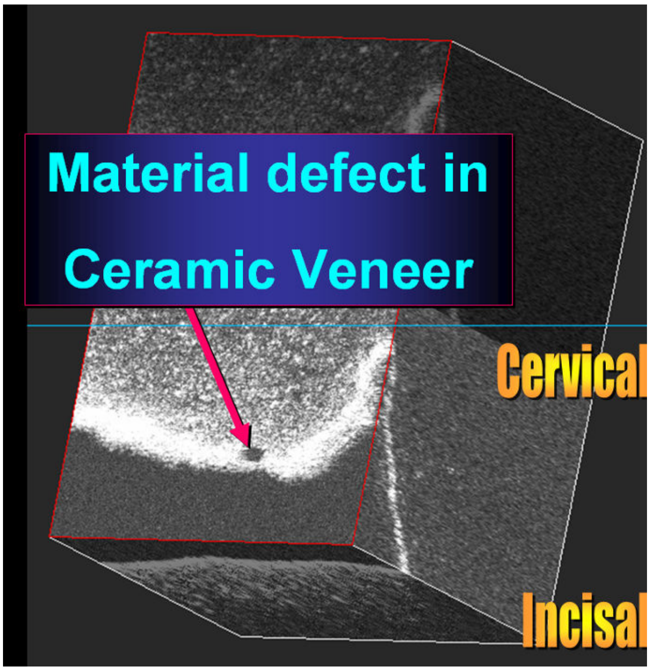

Fig. 10. En Face OCT investigation of ceramic veneer sample nr.3. 3D reconstructions of the 110 stuck images with 18 degree scanning.

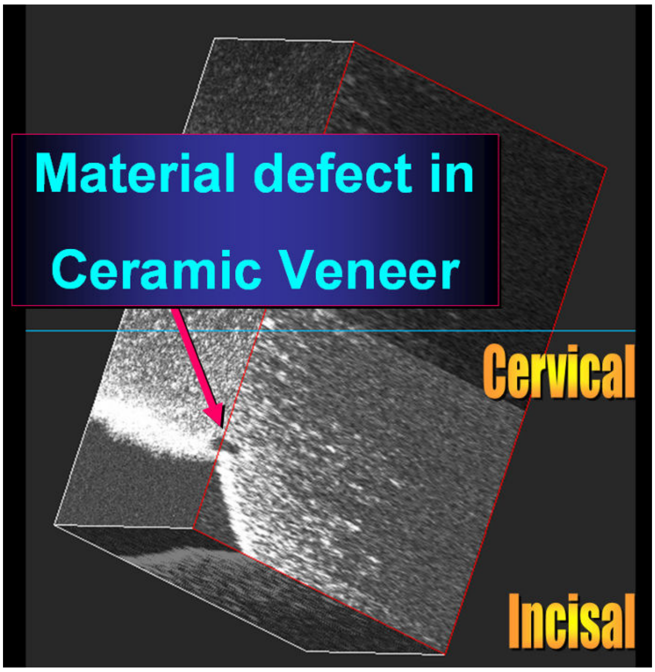

Fig. 11. En Face OCT investigation of ceramic veneer sample nr.3. 3D reconstructions of the 110 stuck images with 18 degree scanning.

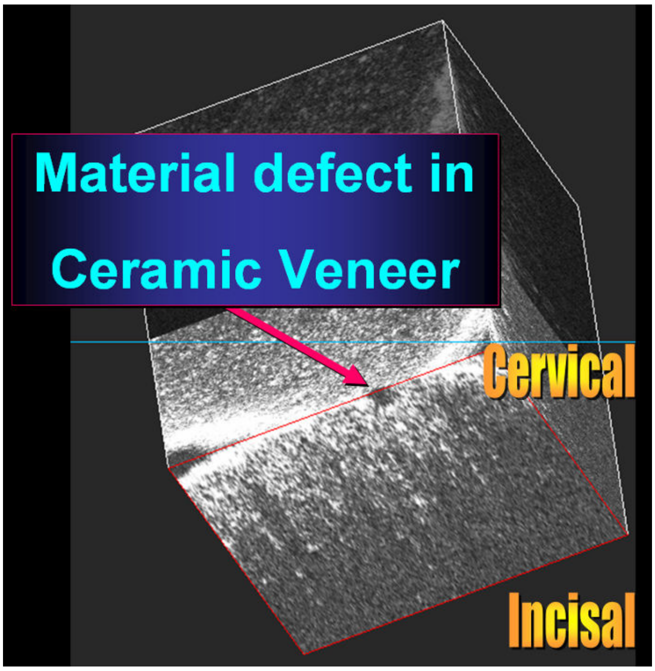

Fig. 12. En Face OCT investigation of ceramic veneer sample nr.3. 3D reconstructions of the 110 stuck images with 18 degree scanning.

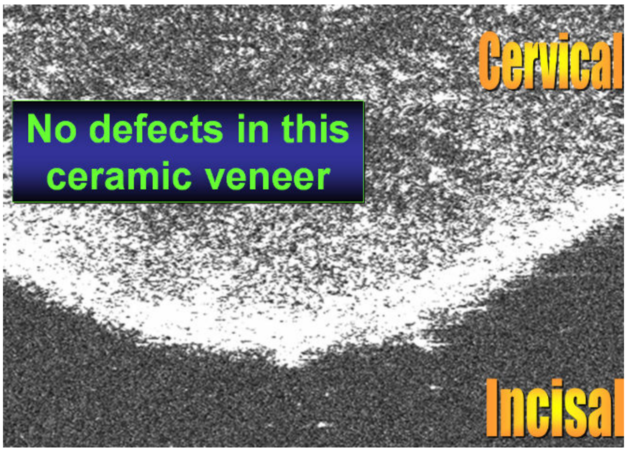

Fig. 13. En Face OCT investigation of ceramic veneer sample nr.7. Slice 27 from 110 stuck images with 18 degree scanning.

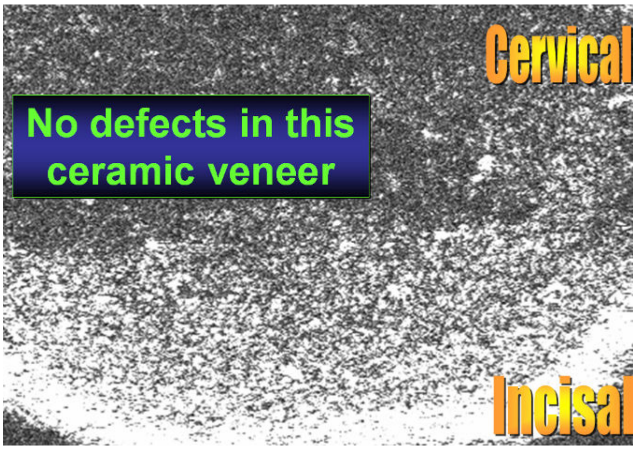

Fig. 14. En Face OCT investigation of ceramic veneer sample nr.7. Slice 36 from 110 stuck images with 18 degree scanning.

The ceramic veneer sample nr.7 revealed no defects inside the structure. The en face scanning was made in incisal, medium and cervical areas in order to have a good evaluation of the sample (Fig. 13 – 14). For a better visualization a three dimensional reconstruction was developed (Fig. 15). The evaluation performed by micro computer tomography validated the results obtained by the optical coherence tomography investigations performed in en face mode. In case of sample nr. 7. the ceramic structure was compact. This kind of investigations performed before inserting and bonding the ceramic veneers in the oral cavity could prevent fractures caused by the stress concentrators from inside the structure that become active in a biomechanical environment.

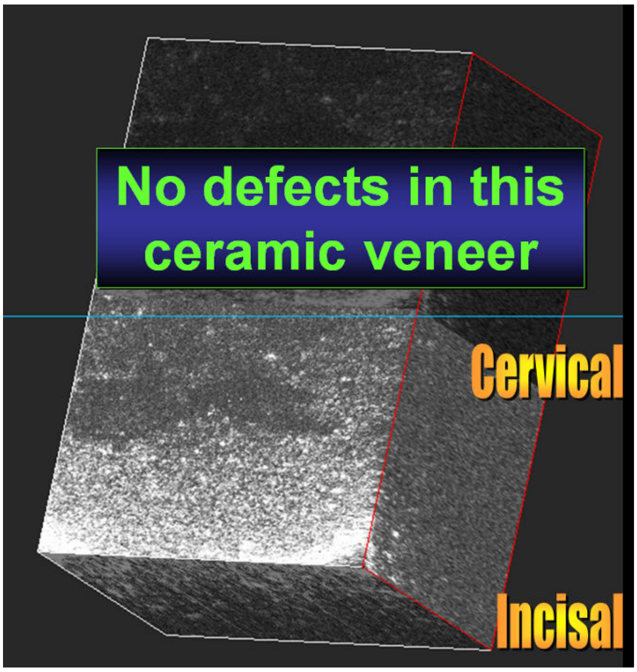

Fig. 15. En Face OCT investigation of ceramic veneer sample nr.7. 3D reconstructions of the 110 stuck images with 18 degree scanning.

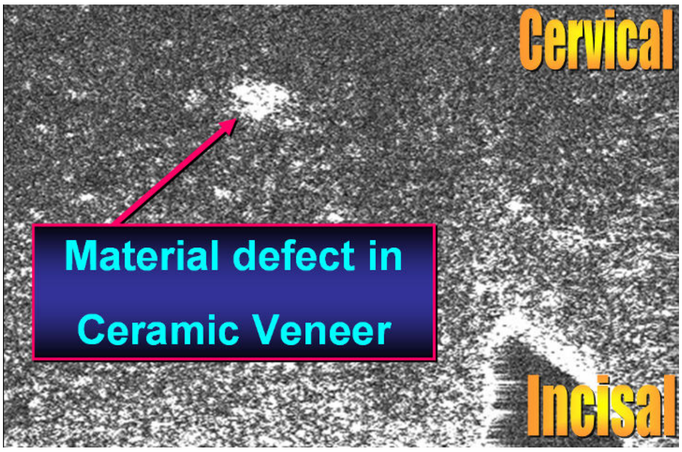

Fig. 16. En Face OCT investigation of ceramic veneer sample nr.9. Slice 49 from 110 stuck images with 18 degree scanning.

In sample nr. 9 the ceramic defect is positioned beside the connection of a two morphological structures (two growing dental lobules) made by the dental technician inside the veneer. The biomechanical stress could easily lead to a fracture line that will connect the material defect with the dental lobules connection. In this case the stress could be much easily transmitted to the ceramic defect (in compare with sample nr. 3) through the connection area positioned in the incisal part of the veneer. The defect is visible on the en face investigation (Fig. 16 – 19) and on the three dimensional reconstructions developed (Fig. 20 - 21).

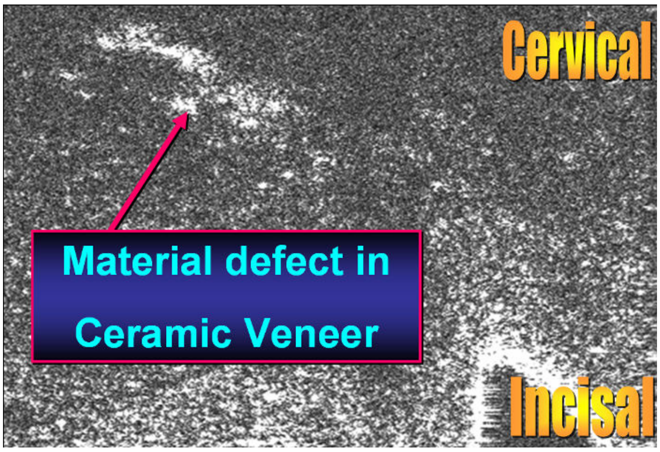

Fig. 17. En Face OCT investigation of ceramic veneer sample nr.9. Slice 53 from 110 stuck images with 18 degree scanning.

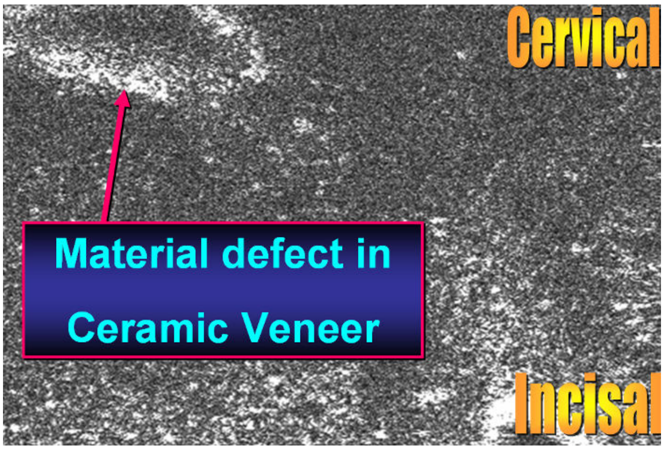

Fig. 18. En Face OCT investigation of ceramic veneer sample nr.9. Slice 62 from 110 stuck images with 18 degree scanning.

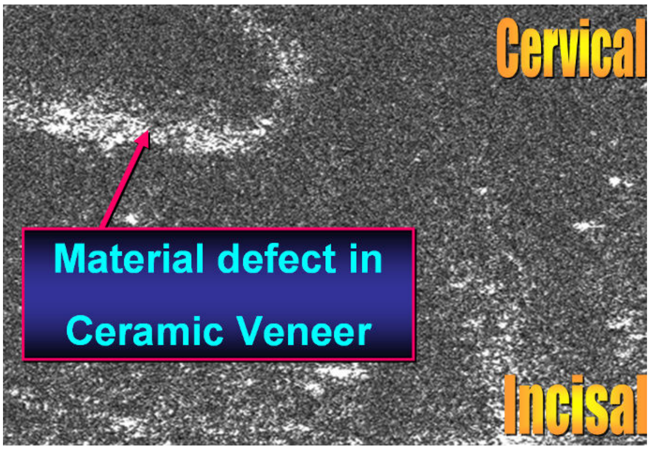

Fig. 19. En Face OCT investigation of ceramic veneer sample nr.9. Slice 70 from 110 stuck images with 18 degree scanning.

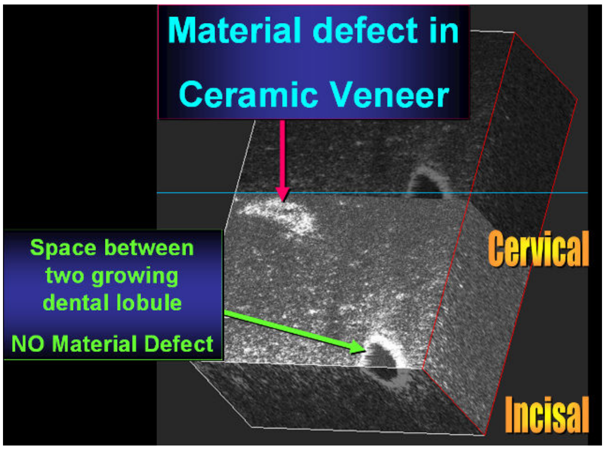

Fig. 20. En Face OCT investigation of ceramic veneer sample nr.9. 3D reconstructions of the 110 stuck images with 18 degree scanning.

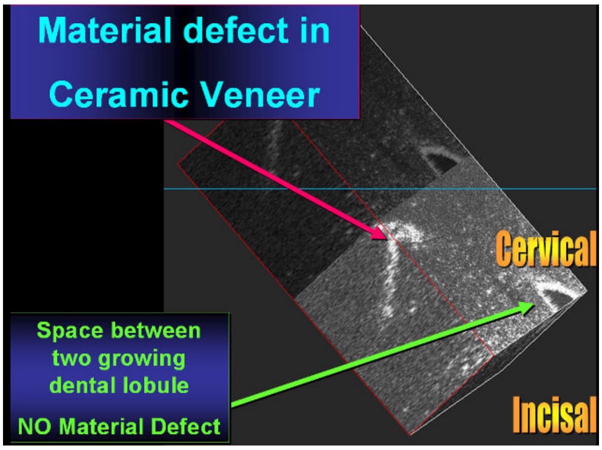

Fig. 21. En Face OCT investigation of ceramic veneer sample nr.9. 3D reconstructions of the 110 stuck images with 18 degree scanning.

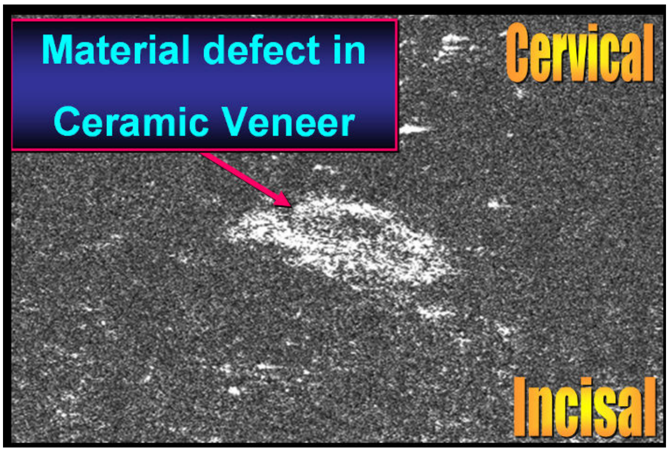

Fig. 22. En Face OCT investigation of ceramic veneer sample nr.10. Slice 72 from 110 stuck images with 18 degree scanning.

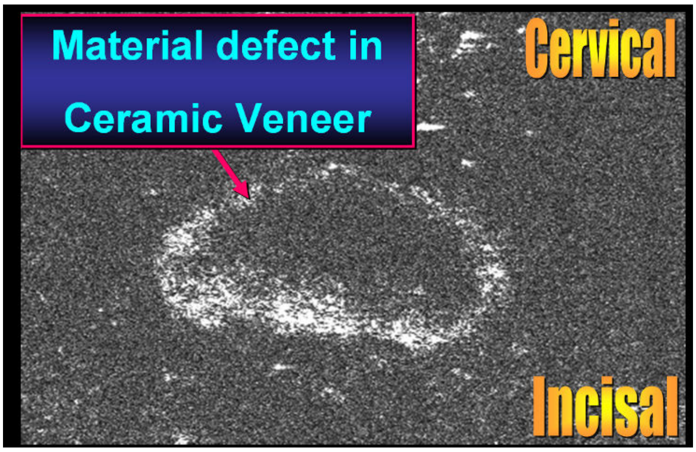

Fig. 23. En Face OCT investigation of ceramic veneer sample nr.10. Slice 83 from 110 stuck images with 18 degree scanning.

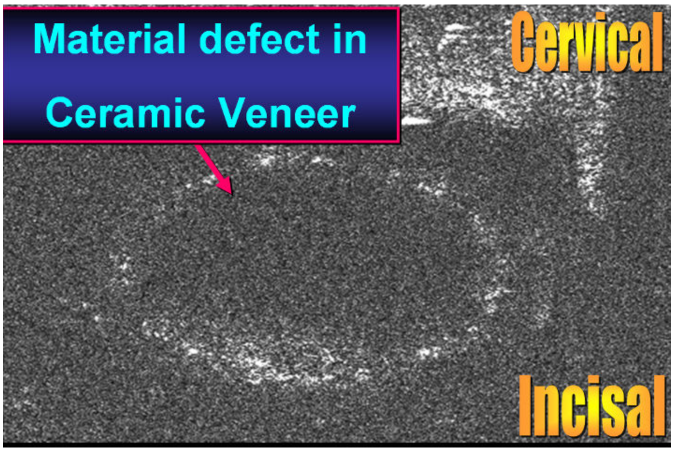

Fig. 24. En Face OCT investigation of ceramic veneer sample nr.10. Slice 93 from 110 stuck images with 18 degree scanning.

The stress concentrator was identified in the middle part of the veneer for the ceramic sample nr. 10. En face investigations revealed a big aeric inclusion that almost goes to the other part of the ceramic veneer (Fig. 22 – 24). For a small defect, in this part of the ceramic veneer, the biomechanical stress affect less the structure in compare with defects depicted in samples nr. 3 and sample nr. 9. In this case the volume of the defect is very big and the stress concentration transmitted from the incisal area will fracture in two the sample. Three dimensional reconstructions were developed for this sample (Fig. 25 – 26).

For the sample nr. 3, nr. 9 and nr.10 it is important to repeat the technological procedures in order to obtain ceramic veneers that could be bonded in the oral cavity and having a good biomechanical behavior. Some time trying to fix the ceramic defects could be a good solution but an accurate evaluation of the defect morphology is required in order to fill all the defects volumes with ceramic materials.

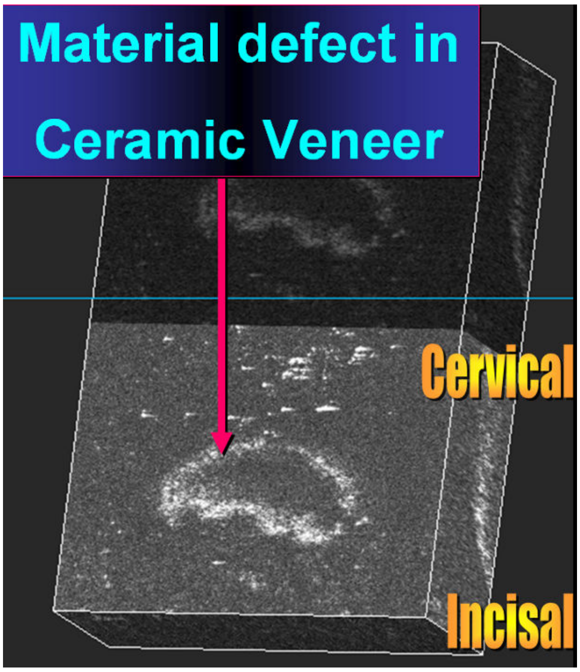

Fig. 25. En Face OCT investigation of ceramic veneer sample nr.10. 3D reconstructions of the 110 stuck images with 18 degree scanning.

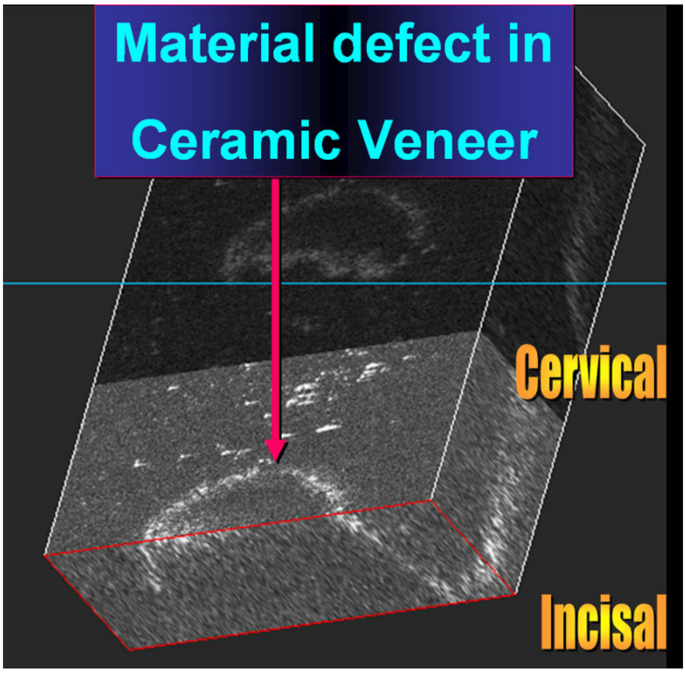

Fig. 26. En Face OCT investigation of ceramic veneer sample nr.10. 3D reconstructions of the 110 stuck images with 18 degree scanning.

V. Conclusions

OCT could act as a valuable noninvasive method in analyzing the integrity of prostheses. This will save time and resources by eliminating prostheses with defects before they are mounted in the patient's oral cavity. The results obtained with the OCT working in Time Domain were validating by MicroCT investigations.

Acknowledgments

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