

Use of optical coherence tomography in orthodontics

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Abstract. Optical coherence tomography (OCT) is a modern imaging method with applicability in orthodontics. In recent years, there has been an increasing trend in the use of ceramic brackets. The aim of the present study was to investigate the effects of bonding metallic and ceramic brackets on tooth enamel, using optical coherence tomography. For this purpose, 20 permanent teeth were bonded and were subsequently debonded using a side cutter or anterior bracket removal pliers. Using the OCT technique, the enamel, the amount of adhesive remaining and the bracket fragments remaining on the tooth surface were analyzed following the debonding procedure. It was demonstrated that enamel cracks were present only in the samples bonded with ceramic brackets. At the same time, it was noted that the type of pliers did not affect the incidence and extent of damage to the enamel. The type of debonding technique (using the side cutter or the anterior removal pliers) used did not markedly affect the amount of adhesive remaining on the teeth. Thus, as demonstrated herein, by analyzing the enamel structure through the use of OCT, the quality of the processes and the materials used for manufacturing brackets can be increased.

Introduction

Optical coherence tomography (OCT) can be defined as a modern imaging investigation technique. This technique is effective in visualizing the differences in the optical properties of tissues. OCT has both optical absorption and optical reflection properties (1).

OCT was introduced into the medical field >20 years ago and was initially used for structural and functional investigations of the eye by ophthalmologists (2-4). The use of OCT technologies has increased in recent years in various medical domains, such as gastroenterology, dermatology and neurology (5-12). Recently, OCT has been used in dental medicine and particularly in orthodontics. There are a multitude of uses for OCT in the field of dentistry, such as for the anatomical examination of dental and periodontal structures, for the qualitative and quantitative evaluation of the resins used in the bonding procedure, for the examination of the biofilm formed around the brackets, and for the evaluation of periodontal ligament responses to various orthodontic forces generated during treatment (13-16).

The most crucial advancements in orthodontics were made with the introduction of acid etching, followed by the direct bonding of the brackets on the enamel surface, using an epoxy resin. This technique was described by Newman in 1965 (17). Currently, the adhesive systems used in orthodontics are based on Bowen's bisphenol A-glycidyl methacrylate (Bis-GMA) resin. This resin is available in a wide variety of viscosities for easy penetration into the etched enamel surfaces (18).

At the end of the orthodontic treatment period with fixed appliances, a crucial step is the bracket debonding procedure. During this step, particular attention should be paid to the removal of all adhesive resin from the enamel surface. The orthodontist should also aim to restore the tooth surface to its pre-treatment condition as much as possible.

Bracket debonding is one of several causes of iatrogenic damage to enamel. The evaluations of this procedure are commonly performed using an optical microscope; however, this method ensures that only the enamel surface is analyzed. OCT is a high-resolution optical technique that allows the minimally invasive visualization of near-surface alterations in complex tissues. The applications of OCT in dental medicine are related to both hard and soft tissue analysis.

Based on low coherence interferometry using broadband light, the OCT investigation can provide real-time structural images of the enamel and of the soft parts. Currently, this imaging technique can be used to detect the morphological changes of oral tissues *in vivo*. It is also applicable in the diagnosis of early tooth lesions, in assessing the progression of periodontal disease and in detecting oral cancer (19,20).

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Materials and methods

The present study was approved by the Ethics Committee of the University of Medicine and Pharmacy of Craiova, Romania (approval reference no. 72/07.09.2020), in accordance with the ethical guidelines for research with human participants of the University of Medicine and Pharmacy of Craiova, Romania. Written informed consent was obtained from all subjects involved in the study. The present study was performed on a total of 20 permanent teeth extracted at the Oral and Maxillofacial Surgery Clinic of the Clinical Emergency County Hospital of Craiova, Romania. These teeth did not exhibit carious lesions, attrition/abrasion, cracks, or staining (when examined visually and using OCT).

The extracted teeth used in the present study were rinsed with water and then disinfected with 10% H₂O₂ for 10 min. Following the disinfection process, each tooth sample was scaled and polished to remove gingival tissue. To avoid desiccation, the samples were maintained in deionized water until the brackets were bonded. The present study used metallic brackets/Legend medium (GC Orthodontics, Inc.) and ceramic brackets/Ceramic-1 (Changsha Denxy Technology Co., Ltd.), all with a similar mesh. The teeth were randomly divided into four groups (n=5 per group) depending on the type of bonded bracket and the pliers used for debonding.

Prior to the bonding procedure, the samples were removed from the solution and dried using paper towels. The buccal surface of each tooth was examined using the OCT system manufactured by Thorlabs (OCS1300SS), powered by a swept laser source with a central wavelength of 1,310 nm, a spectral bandwidth of 100 nm and an average power of 12 mW. The device was used for 2D and 3D scans, thus ruling out the possibility of tooth samples with enamel damage.

The enamel surfaces were etched with Trulock™ Etchant Gel (Rocky Mountain Orthodontics) containing 37% phosphoric acid for 20 sec, and then rinsed with water for 10 sec and air-dried. The bonding procedure was performed using Trulock Light Activated Adhesive (Rocky Mountain Orthodontics), following the manufacturer's instructions. The adhesive was light-cured for 20 sec from the incisal/occlusal and cervical sides of the bracket using a 3M™ Elipar™ DeepCure-L LED Curing Light (1,470 mW/cm²; 3M Science) (Fig. 1).

Following the bonding procedure, the tooth samples were stored in deionized water for 24 h. The debonding procedure was performed 24 h after bonding using two different pliers: A side cutter (model T00552, Rocky Mountain Orthodontics) and anterior bracket removal pliers (model 678-219, Hu-Friedy Mfg. Co., LLC). All these procedures were performed by the same operator. Although there are various methods regarding the use of these pliers, the debonding phase was performed following a standardized technique.

The side cutter was positioned diagonally at the bracket base and at the incisal/occlusal and cervical level. The bracket was removed by gently squeezing the pliers and performing an additional clockwise rotational movement. The anterior bracket removal pliers were applied by gripping under the bracket wings at the bracket-enamel interface. By squeezing and tilting the pliers downward, a rotational axis was generated at the lower edge of the bracket, thus detaching it from the enamel surface.

Following the debonding procedure, the teeth were fixed in dental silicone (Optosil Comfort Putty, Kulzer GmbH) and positioned for examination using a stereomicroscope manufactured by Nikon (SMZ745T), equipped with NIS-A AMEAS and NIS-A EDF software (version 4.50) for image and data acquisition and processing.

Subsequently, the samples were also fixed in dental silicone and positioned so that the OCT light beam could fall perpendicularly on the debonded surfaces. Thus, the samples were re-examined using the OCT system, and 2D and 3D images of the surfaces involved were obtained.

The present study used a design that allowed the visualization of the tooth surface at different angles in order to detect enamel cracks, the amount of adhesive remaining and bracket fragments resulting from the debonding procedure. At the same time, healthy teeth surfaces were included as controls for the experiment. Tooth surfaces imaged using the OCT system at widths of 10 mm with a distance of 10 mm and a depth of 3 mm were sampled. The obtained images were processed using ImageJ software (version 1.8.0, National Institutes of Health), which is an open access program.

Results

Following the OCT examination, 512 images were obtained for each tooth surface subjected to the debonding procedure. From these, the most representative images were selected, both for the teeth bonded with metallic brackets and for those bonded with ceramic brackets. Those images in which the OCT image was well outlined to be relevant were considered, given that the OCT beam did not always fall perpendicular due to the convexities of the dental surfaces (Fig. 2).

As illustrated in Fig. 2A, the impression left by the sole of the metallic bracket on the surface of the adhesive and small areas where the adhesive came off with the bracket were noted. It was also noted that the adhesive came off almost completely with the ceramic bracket and some adhesive fragments were observed in the areas corresponding to the periphery of the bracket (Fig. 2B).

Following the processing of all the data obtained in the study, it was noted that the metallic brackets generated a larger amount of remaining adhesive on the enamel surfaces compared with that on the ceramic surfaces (Fig. 3). It was observed that cracks appeared only at the tooth surfaces bonded with ceramic brackets and that the type of pliers used for debonding did not influence the incidence and extent of enamel damage. In addition, the OCT images assisted in the evaluation of the size and orientation of the enamel cracks.

As shown in Fig. 3A and C, it was observed that a large amount of the adhesive used for the bonding procedure remained on the enamel surface after bracket debonding. Although the sole of the metallic brackets has a mesh in order to increase mechanical retention, the adhesive adhered more effectively to the enamel surface. In the OCT images, the irregular surface of the adhesive which remained after bracket debonding was observed. The debonding of metallic brackets from dental surfaces does not cause cracks; however, it generates larger amounts of adhesive remnant. This increases the risk of damage to the enamel during conventional adhesive removal techniques with tungsten carbide burs.

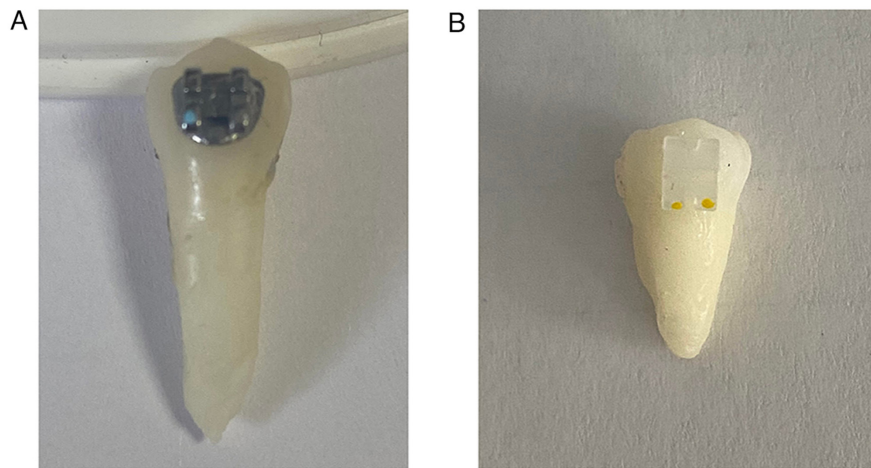


Figure 1. Macroscopic images (magnification, x2.50) of a tooth bonded with a (A) metallic bracket and (B) ceramic bracket.

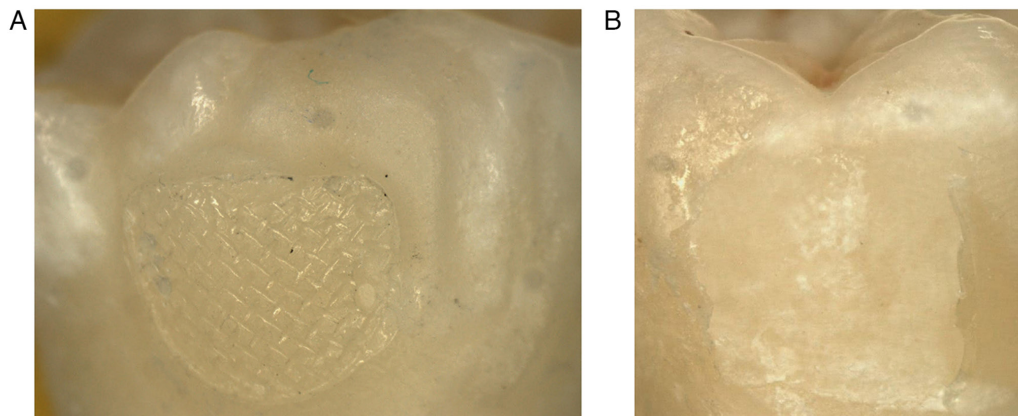


Figure 2. Stereomicroscope imaging (magnification, x30) of the buccal area following the debonding procedure of a (A) metallic bracket and (B) ceramic bracket.

As shown in Fig. 3B and D, cracks on the enamel surface and small amounts of adhesive remnants were noted. The aspects that were observed following the debonding technique highlighted the strong adhering ability of the adhesive to the dental surfaces. As regards the ceramic brackets, the adhesive adhered more effectively to the mesh from their soles as compared to that of the metallic ones. The debonding procedure generated marked detachment forces, causing enamel cracks.

Following the debonding procedure, only fragments of ceramic brackets remained on the enamel surface. It was found that the side cutter generated fractures of the ceramic brackets more frequently than the anterior bracket removal pliers. Both pliers used in the present experiment generated variable amounts of remaining adhesive on the enamel surface.

Discussion

OCT is a tomographic imaging procedure capable of reproducing high-resolution sectional images of the internal architecture of materials and tissues (1-2 mm depth). With the aid of the OCT technique, images of both normal and pathological hard dental structures can be examined, and the quality of

various types of dental treatments can be investigated (21,22). This imaging technique has an increased sensitivity compared with other investigative methods used for this purpose (23).

The majority of studies on the changes of hard dental tissues associated with fixed orthodontic therapy have been performed *in vitro* on teeth extracted from bovines or humans using scanning electron microscopy, surface profilometry and laser fluorescence (24-27). These studies prompted the authors to conduct an *in vitro* study on the structural changes caused by the bracket debonding procedure. However, studies conducted using OCT technology are limited. The resolutions (for air) of the OCT system used in the present study were 12 μm for axial and 15 μm for lateral resolutions. The system allowed for the analysis of a sample of 10x10x3 mm (length, width and depth, respectively) or 1,024x1,024x512 pixels in approximately 30 sec, using a charge-coupled device-type detector (28,29).

As regards the etching of the dental surfaces in order to bond the brackets, the present study used Trulock Etchant Gel, which is effective on both dentin and enamel. This adhesive system is mainly recommended to patients with poor oral hygiene and, implicitly, with enamel demineralization. Over time, these patients have posed real challenges for orthodontists, as the quality of bracket adhesion on such enamel is

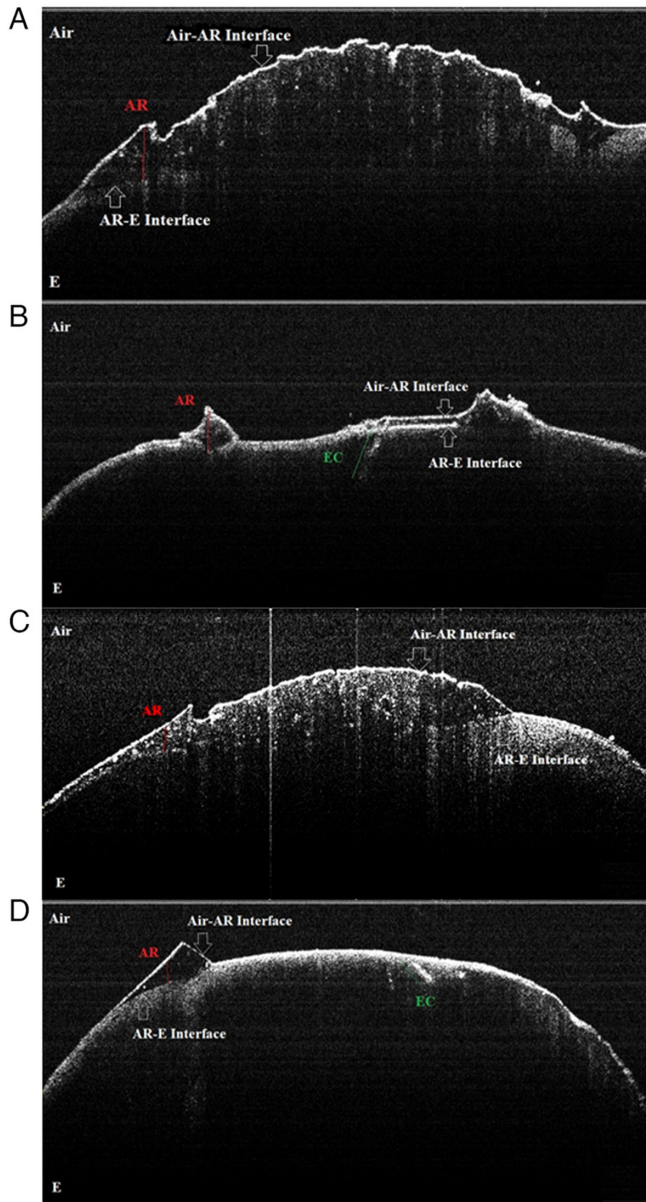


Figure 3. Optical coherence tomography imaging of the buccal area following the debonding procedure of a (A and C) metallic bracket and (B and D) ceramic bracket. E, enamel; AR, adhesive remnant; EC, enamel crack.

poor (30). The viscosity of the gel prevents it from leaking from tooth surfaces and can also be easily removed without leaving residue.

For the bonding procedure, Trulock Light Activated Adhesive was selected, as it is single-paste resin-based, thus avoiding the deficiencies caused by conventional two-component systems. The one-component adhesive reduces the risk of accidental bracket debonding and significantly reduces the working time. This adhesive system contains fluoride, which reduces the risk of demineralization and even carious processes around the brackets. These are used in patients with poor oral hygiene, with the fixed orthodontic appliances promoting plaque retention (31).

The integration of fluoride in the adhesive systems for bracket bonding has proven to be an extremely useful measure in preventing dental demineralization following

fixed orthodontic treatment (32). The Trulock Light Activated Adhesive is designed to bond metallic, ceramic and plastic brackets. The etching technique (followed by the infiltration of the adhesive resin into the surface layer of the enamel during the bonding procedure) renders it impossible to restore the initial status of the enamel following the completion of orthodontic treatment (33).

Thus, bracket debonding is an orthodontic procedure with an increased risk of damage to the enamel in the form of scratches, cracks or tissue loss. To protect this structure, orthodontists need to use procedures that prevent failures at the enamel-adhesive interface, leaving as much adhesive on the tooth surface as possible. It has been demonstrated that maintaining the structural integrity of the enamel is dependent on the presence of large amounts of remaining adhesive. Modern adhesive technologies seem to be a favorable solution that facilitates orthodontic treatment and yields promising results (34).

The present study used two types of orthodontic pliers: A side cutter and an anterior bracket removal pliers. Both pliers are made of high-quality stainless steel. The side cutter is used for both cutting orthodontic wires and for removing brackets. The anterior bracket removal pliers have a single use, to remove brackets from the anterior zone. These pliers were selected for a variety of reasons: The materials they are composed of, the joint and handle construction and the design of the active parts. The handles are designed to allow an optimal grip. The two arms are joined by a sliding joint, resistant to corrosion, which allows the two active parts to create a perfect alignment. The active parts are narrow and composed of tungsten carbide to facilitate their insertion at the junction between the tooth and the bracket sole. Tungsten carbide is approximately twice as stiff as steel. This property is an important feature of the active parts. These qualities ensure the longevity of the pliers and facilitate the process of bracket debonding. Given that the side cutter is often used to cut orthodontic wires, its active parts are sharpened from those of the anterior bracket removal. For this reason, when using the side cutter for the debonding procedure, the risk of fracturing the ceramic brackets is higher (35). Beginning from this premise, it was decided that the bracket debonding procedure would be performed using a standardized technique in the present study (36). Enamel cracks are difficult to visualize and are often overlooked. They can subsequently lead to the appearance of dental hypersensitivity and pain when chewing, symptoms that dissipate when the stimulus is removed (37,38). The demineralization of the adjacent enamel caused by fixed appliances is an undesirable complication of orthodontic treatment, particularly if it is not detected at an early stage and no remedial action is taken (39).

Previous studies based on OCT imaging have analyzed and compared the quality of the bonding procedure of ceramic and polymeric brackets. The aim of these studies was to evaluate the adhesive film between the bracket sole and the dental surface. Unlike the present study, the OCT analysis of the samples was performed following the bonding technique, observing the defects in the adhesive structure. It was concluded that these gaps may also be the consequence of a human error during the bonding procedure. On the other hand, additional research

is required to demonstrate the effectiveness of the indirect bonding technique compared with the direct one (40,41).

Another study performing the OCT analysis of the tooth surfaces following bracket debonding concluded that the removal of adhesive remnant increased the roughness of the enamel in accordance with the technique used in this operation. Thus, tungsten carbide burs generated the roughest surfaces, while the use of Adhesive Residue Remover led to the smoothest surfaces (42). It was further demonstrated that the type of tooth on which the bracket is bonded plays an important role (43). Similar to the present study, these studies indicate the importance of OCT in the field of fixed orthodontics (42,43).

A previous clinical study demonstrated that both metallic and ceramic brackets have a similar failure rate (44). Although *in vitro* studies have indicated that enamel cracks are potential gateways for microorganisms, an infection of the endodontic system is unlikely to occur if the dental pulp is healthy. The risk of pulp necrosis generated by enamel cracks is 3.5% (45). Previous clinical studies have demonstrated that if a tooth with enamel cracks and reversible pulpitis is diagnosed at an early stage, it can be recovered by applying a micro-prosthesis, with endodontic treatment being necessary in only 20% of these cases in 6 months (46,47). This finding indicates the importance of the early identification of enamel cracks with the aid of OCT technology, which would facilitate the diagnosis and early treatment of dental hypersensitivity in current practice.

Studies have determined that maintaining the structural integrity of the enamel is closely dependent on the presence of large amounts of adhesive (19,48). In the present study, both pliers used generated variable amounts of adhesive remnants on the enamel surfaces. Thus, the type of pliers did not affect the extent of the enamel damage. The results of the present study are similar to those of other studies (19,36). However, a previous study performed on a small number of samples (n=6) demonstrated that the side cutter led to bond failures at the enamel-adhesive interface, while the anterior bracket removal pliers led to bond failures at the bracket adhesive interface (49).

Ceramic brackets are extremely fragile, and thus a small amount of energy may be sufficient to fracture them (50). From a clinical point of view, the fracture of a ceramic bracket is undesirable, as the presence of bracket fragments on the tooth surface hampers the polishing of the enamel (51). The present study found that the side cutters caused fractures of ceramic brackets more frequently than the anterior bracket removal pliers.

Other studies have also demonstrated that enamel cracks appeared only during the debonding of ceramic brackets, revealing a greater risk of damage from this procedure compared with the debonding of metallic brackets. This aspect can be explained by the fact that the composite system used for the bonding procedure adheres strongly to both surfaces (the enamel and ceramic bracket mesh) (52,53).

Particular attention should be paid to the debonding procedure. Following the bracket removal technique, there should be no adhesive resin remaining on the enamel surface. This step needs to be performed without causing enamel damage. This objective is as important as the other objectives of the fixed orthodontic treatment: The correction of the malocclusion and the re-education of the functions of the dento-maxillary apparatus (mastication, deglutition, respiratory function,

speech and facial esthetics), as enamel damage can endanger the vitality of the tooth.

In conclusion, the present study demonstrated that the side cutter produced fractures of the ceramic brackets more frequently than the anterior bracket removal pliers. By contrast, the type of pliers used for the debonding procedures did not influence the amount of adhesive remaining on the tooth surface. After debonding, metallic brackets generated larger amounts of adhesive remaining on the enamel. Thus, through the OCT analysis of the enamel structure, the quality of the processes and materials used for manufacturing brackets can be increased. In the future, OCT examination may be used *in vivo* to facilitate orthodontic procedures in order to restore the tooth surface to its pre-treatment condition.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

SMSP, MJT, FIM, AGN and ITD made substantial contributions to the conception and design of the study. SMSP, EO, AC, AIS, ITD and ESB made substantial contributions to the acquisition, analysis and interpretation of the data for the study. MJT, AC, ESB and ITD drafted the manuscript and revised it critically for important intellectual content. All authors reviewed the literature findings and critically revised the manuscript and approved the current form of the article in order to be submitted to the journal. MJT and ITD confirm the authenticity of all the raw data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

The present study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethical Committee of the University of Medicine and Pharmacy of Craiova, Romania (decision reference no. 72/07.09.2020). Written informed consent was obtained from all subjects involved in the study.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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