

Evaluation of enamel surface changes by different enamel conditioners and de-bonding procedure using optical coherence tomography: An in-vitro qualitative study

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Abstract

Introduction: The purpose of this study is to evaluate surface changes of enamel after using different enamel conditioning agents and bonding adhesives after de-bonding and clean-up of metal and ceramic brackets using optical coherence tomography.

Method: Metal and ceramic brackets were bonded onto 120 pre-molars, divided into 4 groups [n=30] which were de-bonded after 24 hours. Enamel conditioners, bonding agents and adhesive resins of four different brands were used in each group. The images of enamel surface were captured with Optical Coherence Tomography [OCT] machine; pre-treatment (T0), post-etching (T1), after bracket de-bonding (T2) and post-cleanup (T3). A spectral domain optical coherence tomography system with 5µm axial spatial resolution was used. This was connected to a pre-configured computer system. A total of 480 images were evaluated for enamel surface evaluation.

Results: OCT images obtained allowed us to evaluate the enamel surface after acid-etching and post de-bonding and clean-up procedures. 2D OCT analysis allowed in-depth analysis of enamel loss after various procedures. OCT also assisted in locating remnant adhesive layer after clean-up.

Conclusion: OCT is a powerful clinical tool for the use in dentistry and can be used effectively to evaluate enamel surface loss after various procedures.

Keywords: De-bonding Evaluation using Optical coherence tomography, Evaluation of enamel surface changes, Optical Coherence Tomography, OCT.

Introduction

The world of orthodontics has witnessed giant strides in all facets at an exponential rate. The most significant development was introduction of enamel etching and use of adhesive resin to bond the brackets onto enamel surface of teeth.¹ Etching with 37% phosphoric acid produces micro-porosities into which fluid monomers penetrate.² This simplified the process of orthodontic bonding on to enamel which increased patient compliance.

Although introduction of bracket bonding was a major advancement over banding but it also poses different challenges. The adhesion should be strong enough to prevent bond failure but also weak enough so that enamel damage is minimal. After orthodontic treatment with fixed appliances, bonded brackets and residual adhesive must be removed. Ideally de-bonding should lead to 'restitutio ad integrum' [restoration to original condition] as close to its pre-treatment condition.³ The procedure of de-bonding has potential risk of caries, scarring, scratches, loss of enamel and retention of resin tags which cause irreversible alteration of enamel.^{2,4}

During bracket removal, bond failure occurs at adhesive-enamel-bracket interface (adhesive) or within the adhesive (cohesive failure), certain amount of enamel loss is inevitable.³⁻⁵ Evidences from in-vitro

studies are without considering major factors like saliva, masticatory forces, temperature, pH changes. De-bonding methods range from electro-thermal de-bracketing, laser de-bonding to de-bonding with conventional pliers as removal of residual resin from tooth surface without iatrogenic damage is the primary concern.^{6,7}

The concern for enamel damage is critical especially when de-bonding involves ceramic brackets. Ceramic brackets have greater strength existing as mono or poly-crystalline. They have low fracture toughness than metal bracket and are more likely to shatter during de-bonding.⁷

The characterization of enamel surface after de-bonding are done by examination of teeth under 10 X or 16 X magnification,⁸ using disclosing medium,⁶ polarized digital imaging,⁹ optical stereomicroscope,¹⁰ 3D laser scanning,^{11,12} scanning electron microscopy,^{3,13,14} SEM microphotographs,¹⁵ 3D surface profilometry¹⁶ and transillumination.¹⁷

Optical Coherence Tomography (OCT) is a well established technique that gives high resolution, ultra-fast, non-invasive and cross-sectional tomographic imaging of tissue micro-structures. It is analogous to ultrasound imaging technique as it analyzes reflected wave from tissue and carries structural information of biologic sample.⁴

A high potential of low coherence interferometric (interference of light) technique provides thin section from tissues, so this technology was termed as ‘Optical Coherence Tomography’.¹⁸

OCT was initially explored for ophthalmological purposes, but now used in fields of dermatology, endoscopy, cardiology, gynecology, oncology, urology and otolaryngology.⁴

In dentistry, OCT is successfully used for evaluating the severity of incipient and advanced carious lesions. In periodontics, OCT provides surface topography, pocket morphology and attachment levels and also pinpoints disease progression sites, root surface irregularities and distribution of sub-gingival calculus. OCT has improved the clinical evaluation of peri-implant soft tissue before significant osseous destruction in prosthetics, revealing poor marginal adaptation of fixed prosthesis.¹⁸

Literature on applications of OCT for orthodontic purposes is very scarce. Not many studies are performed on evaluation of enamel surface after de-bonding. Hence, the purpose of this study is to evaluate surface changes of enamel after using different enamel conditioning agents and bonding adhesives after de-bonding of metal and ceramic brackets using optical coherence tomography.

Materials and Methods

The study consisted of 120 pre-molars divided into four groups extracted for orthodontic purposes, stored

in thymol solution (0.1% wt/vol) to prevent dehydration and bacterial growth. Each tooth was thoroughly scaled to remove calculus and soft-tissue debris followed by thorough prophylaxis with pumice on rubber cup mounted on a slow-speed contra-angle headpiece. The extracted pre-molars were mounted in cold cure acrylic resin of blocks 2 X 2 square cm. Clear acrylic resin block for bonding ceramic brackets while pink acrylic resin block for bonding metal brackets. Adhesive tapes of blue, green, red and yellow color were wrapped around acrylic blocks for identification of samples of group I, II, III and IV respectively.

The buccal surfaces of the teeth were examined (T0) under OCT machine and evaluated for characterization of enamel surface structure to obtain initial images of intact enamel.

Maxillary and mandibular pre-molars extracted for orthodontic reasons with intact buccal surfaces having sound coronal surface were included in the study while pre-molars with large restorations, fracture during extraction, caries or decay, macroscopic cracks, abrasions or hypo-calcified enamel or prior exposure to chemicals which may affect the strength of the enamel were excluded.

The teeth were divided into four groups - group I, II, III and IV [n=30 each]; depending upon the enamel conditioning agent used for etching the teeth, primer and the bonding adhesive used for bonding the metal and ceramic brackets on pre-molars (Table 1).

Table 1: Enamel conditioners and Adhesive resins used in all 4 groups

	Enamel Conditioner used	Primer & Adhesive Resin used
Group I	3M Unitek	Transbond XT- 3M Unitek
Group II	Ivoclar Vivadent	Tetric N-Bond- Ivoclar Vivadent
Group III	Ortho Etch (d tech)	Assure Plus & Rely-a-Bond- Reliance
Group IV	ETC 37 MAARC	Ormco- Enlight

Table 2: Enamel loss after etching and clean-up in all 4 groups

Procedure	Group	Mean Values (µm)	SD
After Enamel Conditioning	I	6.4950	0.91949
	II	6.1543	1.00883
	III	11.9263	1.78515
	IV	6.8307	1.12504
Clean-up after de-bonding of metal brackets	I	65.8973	6.15163
	II	49.5713	9.98675
	III	73.2393	4.85879
	IV	73.4747	3.99228
Clean-up after de-bonding of ceramic brackets	I	150.2467	31.33551
	II	98.4673	17.19263
	III	142.2000	10.88735
	IV	157.1800	10.68545

Bonding Procedure: Enamel conditioning was carried out with 37% phosphoric acid solution in all groups for 30 seconds with etchants of four different brands. The etchant was then rinsed off with an air-water spray for 30 seconds and then air dried. The enamel surface was

again evaluated (T1) for surface topography and roughness after etching. A thin uniform coat of bonding agent/ primer was applied on the enamel surface with an applicator and then light cured.

Out of 30 samples in each group- 15 pre-molars were bonded with metal brackets (Modern Orthodontics) and remaining 15 were bonded with ceramic brackets (Koden Basic).

A small amount of adhesive resin was placed on base of the uncoated brackets in strict accordance with the manufacturer's instructions. The brackets were then placed on the tooth surfaces, adjusted to their final positions. After removal of excess resin from the periphery of the bracket base, light curing was done for 20 seconds by using a rechargeable LED curing light (LY-C240, Unicorn; DenMart).

All the specimen were then stored in artificial saliva for a period of 24 hours at room temperature. De-bonding was carried out after 24 hours by using bracket de-bonding pliers following a standardized procedure – the metal brackets were de-bonded using bracket de-bonding pliers by gripping below the bracket wings at bracket-enamel interface, a rotational axis was created at apical bracket margin, thereby releasing the bracket. The ceramic brackets were de-bonded mechanically using Weingart pliers by gently squeezing of pliers with an additional clockwise rotational movement.

After bracket removal, teeth were again examined (T2) by OCT for a detailed view of the de-bonded surfaces. Residual adhesive on the pre-molars was also

assessed visually, using a modified Adhesive Remnant Index by Artun J and Bergland S¹⁹ which is commonly used in de-bonding studies as it is a simple method to

record the site for bond failure. The scoring criteria are as follows;

Score 0 = No adhesive left on tooth

Score 1 = Less than half of the adhesive left on tooth

Score 2 = More than half of the adhesive left on tooth

Score 3 = All adhesive left on tooth, with distinct impression of bracket mesh.

Residual adhesive removal was done with a low-speed tungsten carbide finishing bur in all the groups; enamel surface was again verified by optical coherence tomography (T3). The OCT images were made to evaluate the surface of the intact enamel before bonding, after etching, after bracket removal and after residual resin removal and final clean-up.

Results

The pre-enamel conditioning images of the buccal surface of the pre-molars by OCT showed typical anatomy of the enamel surface. Most of the tooth surfaces showed smooth surfaces along with characteristic perikymata [Fig. 1].

After acid etching with 37% phosphoric acid in all samples OCT images showed breach in the continuity of smooth surfaces of the enamel [Fig. 2]. The images show micro-cavities of varying depth. Maximum amount of enamel loss was seen with group III (Ortho Etch-d tech). ANOVA test for enamel surface loss between all four groups is highly significant after enamel conditioning. Tukey's Post-hoc test shows highly significant differences when group III values were compared with other groups [Table 3].

Table 3: Tukey's post-hoc test after enamel conditioning of 4 groups. P value = highly significant**

Groups (i)	Groups (j)	Mean Difference (i-j)	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
I	II	.34067	.720	-.5050	1.1864
	III	-5.43133	.000**	-6.2770	-4.5856
	IV	-.33567	.730	-1.1814	.5100
II	I	-.34067	.720	-1.1864	.5050
	III	-5.77200	.000**	-6.6177	-4.9263
	IV	-.67633	.164	-1.5220	.1694
III	I	5.43133	.000**	4.5856	6.2770
	II	5.77200	.000**	4.9263	6.6177
	IV	5.09567	.000**	4.2500	5.9414
IV	I	.33567	.730	-.5100	1.1814
	II	.67633	.164	-.1694	1.5220
	III	-5.09567	.000**	-5.9414	-4.2500

Table 4: Tukey's post-hoc test after de-bonding and clean-up of 4 groups. p value* * = highly significant, * = significant

Dependent Variable	Groups (i)	Groups (j)	Mean Difference (i-j)	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Metal	I	II	16.32600	.000**	9.8921	22.7599
		III	-7.34200	.019*	-13.775	-.9081
		IV	-7.57733	.015*	-14.011	-1.1434
	II	I	-16.32600	.000**	-22.759	-9.8921
		III	-23.66800	.000**	-30.101	-17.234
		IV	-23.90333	.000**	-30.337	-17.469
	III	I	7.34200	.019*	.9081	13.7759
		II	23.66800	.000**	17.234	30.1019
		IV	-.23533	1.000	-6.6693	6.1986
	IV	I	7.57733	.015*	1.1434	14.0113
		II	23.90333	.000**	17.4694	30.3373
		III	.23533	1.000	-6.1986	6.6693
Ceramic	I	II	51.77933	.000**	32.9923	70.5664
		III	8.04667	.670	-10.740	26.8337
		IV	-6.93333	.763	-25.720	11.8537
	II	I	-51.77933	.000**	-70.566	-32.992
		III	-43.73267	.000**	-62.519	-24.945
		IV	-58.71267	.000**	-77.499	-39.925
	III	I	-8.04667	.670	-26.833	10.7404
		II	43.73267	.000**	24.9456	62.5197
		IV	-14.98000	.162	-33.767	3.8070
	IV	I	6.93333	.763	-11.853	25.7204
		II	58.71267	.000**	39.925	77.4997
		III	14.98000	.162	-3.8070	33.7670

After de-bonding of metal brackets, mostly all OCT images showed a typical separation at the bracket-adhesive interface leaving the impression of bracket base meshwork on resin adhered to the enamel surface [Fig. 3A] 1 sample showed partial separation at adhesive resin-tooth interface [Fig. 3B] and 1 sample showed complete separation at enamel-adhesive resin interface from group II [Fig. 3C].

After de-bonding of ceramic brackets, 2 samples from group I showed fracture of the enamel during de-bonding [Fig 4A, 4B]. Mostly all samples showed a typical separation at the adhesive resin-enamel interface, while 2 samples from group III showed separation at adhesive-bracket base [Fig. 4C, 4D]. OCT images after de-bonding of metal and ceramic brackets in all groups showed irregular surface topography of the enamel.

Adhesive Remnant Index was scored following the guidelines given by Artun J and Bergland S^[19]; 54 samples out of 60 metal brackets showed score of 3 i.e. all adhesive resin left on tooth with impression of bracket mesh on the tooth. Only one sample from group II showed score of 0 after de-bonding. All ceramic bracket samples showed score of 0 and 2. Majority of

the brackets showed more than half of the adhesive resin left on the tooth surface after de-bonding.

OCT images showed maximum enamel loss after clean-up of de-bonded metal brackets of 73.4µm seen in group IV while least enamel loss was seen in group II. OCT images post-clean-up of ceramic bracket de-bonding showed maximum enamel loss of 157.1µm in group IV while least enamel loss was seen in group II of 98.46µm.

Tukey's post-hoc test [Table 4] shows highly significant values when group IV was compared with other three groups for enamel loss after de-bonding and clean-up. The enamel loss was more in group IV when compared to other three groups after polishing and clean-up.

The residual resin of all samples was removed with slow-speed tungsten carbide bur. After residual adhesive removal the surfaces appeared clean and smooth however OCT images showed resin remnants for few samples. Optical coherence tomography permits the measurement of thickness of resin remnants; which is not possible by other imaging technique.

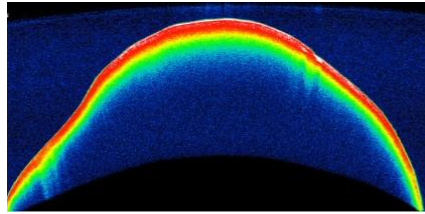


Fig. 1: Pre-treatment

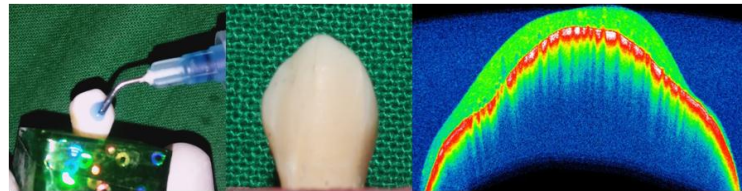


Fig. 2: Post etching with 37% Phosphoric acid

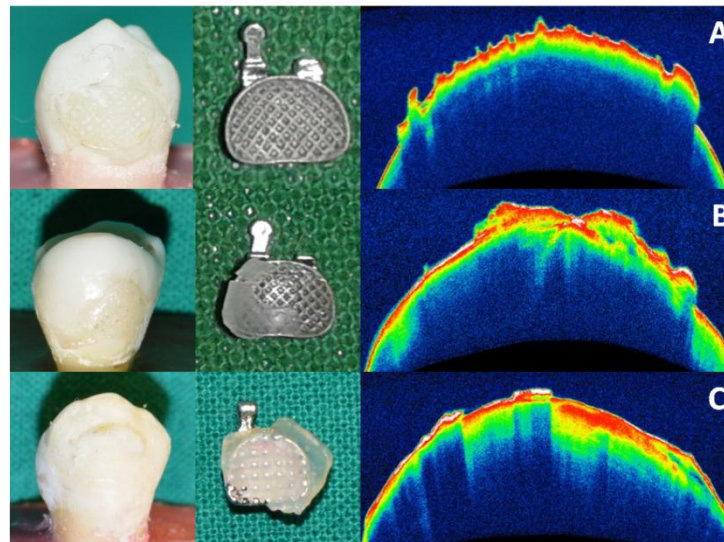


Fig. 3: A, B, C. Clinical and OCT images after de-bonding of metal brackets

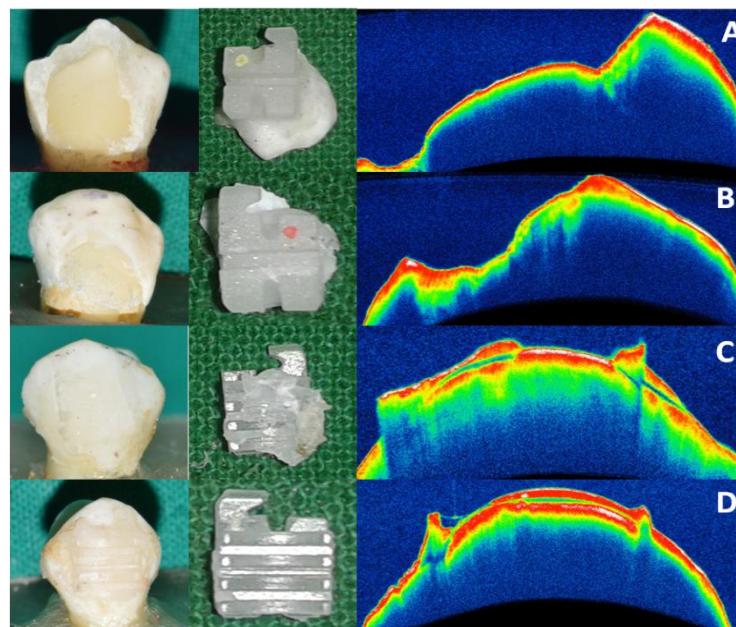


Fig. 4: A, B, C, D. Clinical and OCT images after de-bonding of ceramic brackets

Discussion

The literature is abundantly rich with various experimental studies mostly on extracted pre-molar teeth, regarding bond strength of newer adhesives, potential side-effects of various de-bonding techniques with comparison of techniques for remnant adhesive removal methods.

However, after completion of the orthodontic treatment the finishing procedures usually aim at restoring the topographic enamel surface and preserving the integrity of enamel as close to its pre-treatment condition. Cracks, scratches or enamel fracture are sometimes unavoidable causing irreversible alteration of enamel surface.⁴ Clinically, enamel damage during de-bonding of ceramic brackets are matters of prime concern to an orthodontist.⁵

Primary factors such as etchant used, duration of etching or type of adhesive used can also affect the topography of enamel surface which can indirectly influence bonding and de-bonding; causing damage to enamel surface leaving behind adhesive remnants on the tooth surface. The purpose of this in-vitro qualitative study is to evaluate the surface changes of enamel after using different enamel conditioning agents, after de-bonding and clean-up of metal and ceramic brackets by using optical coherence tomography.

OCT provides in-depth analysis of the scanned structures.⁴ Light in an OCT system is broken into two arms; a sample arm and reference arm. The combination of reflected light from the sample arm and reference light from the reference arm gives rise to an interference pattern. By scanning the mirror in the reference arm, a reflectivity profile of the sample can be obtained. Areas of the sample that reflect back light will create greater interference than areas that don't reflect back. Any light that is outside the short coherence length will not interfere.^{4,20}

OCT facilitates verification of possible enamel damage caused by etching with various conditioners. OCT images after enamel conditioning showed breach in continuity of smooth surfaces of the enamel. The images show micro-cavities of varying depth. Here, enamel conditioning with 37% phosphoric acid caused enamel loss of 6 to 12 μ m. These results are similar to study conducted by Ferreira EF et al²¹ who reported variations in enamel loss of about 4 to 17 μ m.

Metal brackets de-bonded with bracket de-bonding pliers showed a typical separation at the bracket-adhesive interface leaving the resin adhered to the enamel surface for further clean-up and finishing procedures.

Zarrinnia K et al⁵ developed a de-bonding technique which restored the enamel surface to its original condition. Forces applied to base of the bracket and to adhesive created stress concentration regions within the enamel that caused separation at the adhesive-enamel interface. Studies by Ferreira EF et al²¹

and Retief DH and Denys FR^[22] found similar results. OCT images showed residual adhesive resin irregularly adhered on the enamel surface after de-bonding of metallic bracket. Studies by Zarrinnia K et al⁵ and Zannarini M et al²³ stated that de-bonding of metal brackets with bracket de-bonding pliers produces more consistent separation at bracket-adhesive resin interface providing intact enamel surface for clean-up.

De-bonding of ceramic brackets is a concern for an orthodontist as they exhibit extremely high bond strength which can lead to enamel cracks causing cosmetic damage to the patient.^{4, 13} De-bonding of ceramic brackets can be done by Weingarts pliers; tips of the pliers positioned over mesio-distal sides of the wire slot and gentle squeezing induced fracture in center of the slot. It is necessary to gently rock the bracket towards the side that de-bonded first to fully de-bond it; this technique was simple, convenient and can be quickly executed.¹⁰ Ceramic brackets being more brittle in nature tend to fracture during de-bonding owing to high bond strength values up to 28MPa.²⁴ Ceramic brackets are made of high strength materials like alumina, forces applied directly on bracket creates unfavorable stresses resulting in breakage.⁷ Even the smallest surface imperfections significantly reduce the load necessary to fracture a ceramic bracket.^{17, 25}

The remnant adhesive poses a difficulty for clean-up and finishing procedures²⁶ but failure at bracket-adhesive interface indicates safe de-bonding reducing the likelihood of enamel damage.^{8,24} 2D OCT imaging not only permits monitoring of adhesive remnants but also aids in location of ceramic bracket fragments on the enamel surfaces.

The literature shows exuberant studies on restoring enamel surface as close to its original form by using different clean-up procedures but adequate clean-up without enamel loss was difficult to achieve.¹² Greatest enamel loss was seen when ultrasonic scaler was used for adhesive removal^{12,27} while diamond finishing burs were extremely injurious as they produce deep grooves on enamel.^{5,22}

Eminkahyagil N et al¹⁵ concluded that clean-up with high-speed tungsten carbide bur was most hazardous to enamel. Hence, use of slow-speed tungsten carbide bur was done for residual adhesive resin removal.

Clinically, the evaluation of adhesive remnants on the enamel surfaces after de-bonding is usually performed visually. As the 2D images are produced in real time by OCT, it is possible to monitor any remnants during clean-up so that this procedure can be executed as efficiently as possible. OCT imaging can also be used to identify the location of adhesive remnants on the enamel surface.

OCT technology is a very useful tool in clinical practice as it assesses the dental tissues non-invasively providing in-depth analysis of the enamel surface. OCT

machine is highly expensive and multiple 2D scans are required to reconstruct a 3D image which is unlikely. In-vivo studies should be undertaken to characterize the enamel surface after de-bonding to assess it with OCT imaging. Till date the objective of atraumatic de-bonding have not yet been achieved completely. Studies should be demonstrated to use sandblasting and aluminum oxide (Al_2O_3) to reduce enamel surface loss.

Conclusions

1. Characterization of enamel surface topography after etching, de-bonding and clean-up can be performed successfully with optical coherence tomography.
2. We can report in-depth evaluation of adhesive remnants after clean-up and polishing.
3. It is advisable to design different techniques for de-bonding metal and ceramic brackets as no de-bonding technique can be effectively implemented without any enamel loss.
4. The prevalence of enamel damage cannot be overlooked with different enamel conditioners and adhesives; hence bonding materials should be used cautiously.

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