UNIVERSIDADE FEDERAL DE PERNAMBUCO
CENTRO DE CIENCIAS DA SAÚDE
PROGRAMA DE POS GRADUAÇÃO EM ODONTOLOGIA
MESTRADO EM ODONTOLOGIA

Avaliação do esmalte dentário após a descolagem de *brackets* ortodônticos e da remoção da resina remanescente

MÔNICA SCHÄFFER LOPES

Recife – PE

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Dissertação apresentada ao Colegiado da Pós Graduação em Clínica Integrada do Centro de Ciências da Saúde da Universidade Federal de Pernambuco, como requisito parcial para obtenção do grau de mestre em Clínica Odontológica Integrada.

Orientador: Prof. Dr. Anderson S. L. Gomes
Co-orientadora: Prof. Niedje Siqueira de Lima

Recife – PE

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SECRETARIA

Oziclere Sena de Araújo

Ata da 120ª Defesa de Dissertação do Curso de Mestrado em Odontologia com área de Concentração em Clínica Integrada do Centro de Ciências da Saúde da Universidade Federal de Pernambuco. Recife, 08 de agosto de 2012.

Às 10:00(Dez horas) do dia 0(oito) do mês de agosto do ano de dois mil e doze, reuniram-se no auditório do Programa de Pós-Graduação em Odontologia da Universidade Federal de Pernambuco, os membros da Banca Examinadora, composta pelos professores: Prof. Dr. ANDERSON STEVENS LEONIDAS GOMES, atuando como presidente, Prof. Dr. PEDRO PAULO COSTA GONDIM , atuando como primeiro examinador. Profa Dra. MARIA LUIZA DOS ANJOS PONTUAL , atuando como segundo examinador, para julgar o trabalho intitulado **" AVALIAÇÃO DA SUPERFÍCIE DO ESMALTE DENTÁRIO APÓS A DESCOLAGEM DE *BRACKETS* ORDONDONTICOS E DA REMOÇÃO DA RESINA REMANESCENTE",** da CD. MÔNICA SCHAFFER LOPES, candidata ao Grau de Mestre em Odontologia, na Área de Concentração em CLINICA INTEGRADA, sob orientação do Prof. Dr. ANDERSON STEVENS LEONIDAS GOMES e Co-orientação da Profa.Dra. NIEDJE SIQUEIRA LIMA. Dando inicio aos trabalhos o Prof.Dr. ANDERSON STEVENS LEONIDAS GOMES, Membro Permanente do colegiado do Programa de Pós-Graduação em Odontologia, abriu os trabalhos convidando os senhores membros para compor a Banca Examinadora, foram entregues aos presentes cópias das Normas do Curso de Mestrado em Odontologia, que trata dos critérios de avaliação para julgamento da Dissertação de Mestrado. O presidente da mesa após tomar posse conferiu os membros, seguindo convidou a candidata para expor sobre o aludido tema, tendo sido concedido trinta minutos. A candidata expôs o trabalho e em seguida colocou-se à disposição dos Examinadores para argüição. Após o término da argüição os examinadores reuniram-se em secreto para deliberações formais. Ao término da discussão, atribuíram a candidata os seguintes conceitos: Prof. Dr. PEDRO PAULO COSTA GONDIM, (**APROVADA),** Profa. Dra. MARIA LUIZA DOS ANJOS PONTUAL **(APROVADA)** Prof.Dr. ANDERSON STEVENS LEONIDAS GOMES, **(APROVADA), a** candidata recebeu três conceitos**(APROVADA)** é considerada **(APROVADA),** devendo acatar as sugestões da Banca Examinadora, face a aprovação, fica a candidata, apta a receber o Grau de Mestre em Odontologia desde que tenha cumprido as exigências estabelecidas de acordo com o Regimento Interno do Curso, cabendo a Universidade Federal de Pernambuco através de sua Pró-Reitoria para Assuntos de Pesquisa e Pós Graduação, tomar as providências cabíveis. Nada mais havendo a tratar, O Presidente da Banca Examinadora encerrou a sessão e para constar foi lavrada a presente ata que vai por mim assinada , Oziclere Sena de Araújo e pelos demais componentes da Banca Examinadora e pela recém formada mestre pela UFPE**.** MÔNICA SCHAFFER LOPES **.**

Recife, 08 de agosto de 2012.

Prof.Dr. ANDERSON STEVENS LEONIDAS GOMES

Presidente

Prof. Dr. PEDRO PAULO COSTA GONDIM

1º Examinador

Profa. Dra. MARIA LUIZA DOS ANJOS PONTUAL

2º Examinador

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A Deus por iluminar meus pensamentos e me mostrar um bom caminho.

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LISTA DE ABREVIATURAS E SIGLAS

OCT	Optical Coherence Tomography
TCO	Tomografia de Coerência Óptica
SEM	Scanning Electron Microscope
MEV	Microscópio Eletrônico de Varredura
OM	Optical Microscope
MO	Microscópio Optico
ARI	Adesive Remnant Index
IAR	Índice de Adesivo Remanescente
TCB	Tungstene Carbide Bur
BCT	Broca Carbide de Tungstênio
DSL	Diodo superluminescente
EDS	Energy Dispersive Spectroscopy
2D	Axial section images
3D	En-face images

RESUMO

Objetivos: No presente trabalho foi objetivo avaliar a superfície do esmalte após a descolagem de *brackets* ortodônticos e remoção da resina remanescente, por meio da técnica da Tomografia por Coerência Óptica (TCO), em 2D e 3D. **Materiais e Métodos:** Sessenta coroas de incisivos bovinos foram incluídas em resina acrílica, com auxílio de matriz metálica, e em seguida submetidas a polimento manual com lixas d'água com granulações crescentes. A colagem do bracket foi realizada com o sistema TransbondTM XT (3M), e o armazenamento das amostras, em ambiente úmido por 1 semana. No artigo 1, vinte dentes foram divididos (*n=10*) em grupo A, descolagem com alicate 346/ICE e B, descolagem com pistola 346/Zatty. Foram feitas imagens das amostras em Microscópio Óptico (MO) e TCO 3D, e três avaliadores as classificaram quanto o Índice de Adesivo Remanescente (IAR), que posteriormente foi calculado pelo Teste de Kappa. As imagens em TCO 2D serviram para calcular a espessura do ARI e perda de esmalte. No artigo 2, quarenta dentes foram descolados com alicate 346/ICE e sem seguida divididos (*n=10*) em G1, remoção da resina remanescente com broca carbide de tungstênio (BCT) 30 laminas em alta rotação + pasta diamantada e disco de feltro/Diamond; G2,Pontas de fibra de vidro em baixa rotação/TDV; G3,Laser Er:YAG 100 mJ/1.00 W e G4,BCT 30 laminas + polimento com discos de óxido de alumínio/Dhpro. Medidas de rugosidade foram tomadas antes e depois da remoção, bem como imagens em TCO 2D,3D e Microscópio Eletrônico de Varredura (MEV). Foi usado teste estatítisco ANOVA. **Resultados:** O MO e TCO 3D apresentaram 0,83% e 0,70% de concordância no teste de Kappa, respectivamente. Através do TCO 2D, observou-se espessura da resina residual após descolagem do *bracket*, em torno de 164µm (±34 µm). Resultados do IAR mostraram 72,7% em *score 3* e 27,3% em *score 2* no grupo A; e 55,6% em *score 1*, 33,3% em *score 2* e 11,1% em *score 3*, no grupo B. G1, G3 e G4 tiverem rugosidades finais similares, diferente do G2 que apresentou aumento significante ($p<0.05$). Análises da superfície mostraram ranhuras horizontais e verticais no G1 e G4, áreas pontuais de perda mineral no G3. **Conclusões:** MO e TCO 3D foram considerados satisfatórios para mensurar o IAR. TCO 2D foi preciso para medir a espessura de resina remanescente. O grupo do alicate (A) apresentou fratura predominantemente na interface *bracket*/adesivo que preserva mais estrutura de esmalte que o grupo da pistola (B) que a fratura ocorreu frequentemente na interface esmalte/*adesivo*. A remoção da resina remanescente apresenta influencia direta na rugosidade final. Nenhum método de remoção foi considerado perfeito. Laser Er:YAG produziu a maior perda mineral, e a ponta de fibra de vidro não foi capaz de promover um polimento adequado, apresentando a maior rugosidade final. Todos os 3 métodos de avaliação da superfície foram considerados bons para mensurar a perda de esmalte, entretanto, o TCO apresenta a possibilidade de ser aplicada clinicamente.

Palavras-Chave: Esmalte dentário, Braquetes ortodônticos, Tomografia de Coerência Óptica

ABSTRACT

Objective: this present study aimed to assess Optical Coherence Tomography (OCT), through 2D and 3D images as an instrument to evaluate enamel surface after bracket debonding and remnant resin removal techniques. **Material and methods:** Sixty bovine teeth were included in acrylic resin, using metal model as reference, then polished manual com lixas d'água com granulações crescentes. The bracket bonding was done with TransbondTM XT (3M), and then kept in a humid environment during the experimental stages. In article 1, twenty bovine teeth was divided into 2 groups (*n=10*) according to brackets debonding method: A, debonding plier 346 (*ICE*) and B, lift-off debonding instrument 346 (*Zatty*). Remnant adhesives were quantified by 3 evaluators through OM (0.65x) and 3D OCT images; and remnant adhesive thickness and validation of fracture propagation were evaluated by 2D OCT images, and measured by ImageJ software. In the article 2, forty bovine teeth had brackets debonding by plier 346 method, and then divided into 4 groups (*n*=10) according to the clean-up and polishing methods: G1, 30-blade tungsten carbide bur at high speed + diamond paste and felt; G2, fiberglass/TDV points at low speed; G3, Er:YAG laser 100 mJ/1.00 W; G4, 30-blade tungsten carbide bur at high speed + aluminum oxide polishing system/Dhpro. Samples were analyzed previously and after by surface roughness and OCT 2D and 3D, in the end also by scanning electron microscopy, and date were statically analyzed. **Results:** In the article 1, OM and 3D OCT showed 0.83% and 0.70% of agreement in a Kappa statistic test, respectively. The thickness mean of remnant adhesive left by bracket debonding was 164µm (±34 µm). ARI results showed 72,7% *score 3* and 27,3% *score 2* in group A; and 55,6% *score 1*, 33,3% *score 2* and 11,1% *score 3* in group B. In the article 2, G1, G3 e G4 had similar final roughness, different from G2 that presented a significant increase ($p<0.05$). Surface analysis, showed horizontal and vertical scratches for G1 and G4, punctual areas of mineral loss in G3. **Conclusions:** MO and 3D OCT were considered satisfactory to measure ARI. 2D OCT was precisely to measure thickness of remnant adhesive or enamel loss. Bracket debonding by plier has bond fracture predominantly at bracket/adhesive interface which preserves more enamel structure than debonding by lift-off instrument where bond fracture occurred mostly at enamel/adhesive interface. Clean-up of the enamel surface after bracket debonding directly influences surface roughness. No clean-up method was considered perfect. The Er:YAG laser produced the highest enamel loss. And the use of fiberglass was not capable of adequately polishing, increasing final enamel surface roughness. All methods used to assess enamel surface, each with its own characteristics, were considered good for assess enamel surface. However, among the methods studied, OCT has the possibility of being applied clinically.

Key-words: Dental Enamel; Orthodontic Brackets, Optical Coherence Tomography.

1 Introdução

1. INTRODUÇÃO

Existem etapas no tratamento ortodôntico que podem ser potencialmente danosas ao esmalte dentário, devendo os profissionais de Odontologia, como os ortodontistas, atentar para alguns procedimentos. Danos provocados no esmalte por ranhuras, desgastes ou fraturas são quase sempre irreversíveis, principalmente se removem a sua camada mais superficial. Os vinte primeiros micrômetros do esmalte apresentam altas concentrações de fluoretos - importantes para a manutenção e proteção do esmalte (OGAARD, 2001; KITAHARA-CÉIA, 2008; PONT, 2010; SABATOSKI, 2010; KARAN, 2010).

Dentre os procedimentos mais danosos do tratamento ortodôntico estão a descolagem de brackets e a remoção da resina remanescente. Durante os últimos anos, muitos estudos se dedicaram a avaliar técnicas que minimizassem os danos nessas etapas. Contudo, em todos os trabalhos selecionados neste estudo, existiram danos ao esmalte em diferentes graus. Diante disto, ainda hoje existe uma busca constante por técnicas menos invasivas (PIGNATTA, 2006), capazes de restaurar a superfície de esmalte o mais próximo possível da condição de pré-tratamento (TAVARES, 2006).

Das técnicas mais utilizadas clinicamente para descolagem de *brackets* ortodônticos, estão os alicates e a pistola removedora de *bracket*. Para a remoção da resina remanescente, encontram-se as pontas diamantadas (OLIVEIRA, 2006; PITHON, 2008; JUNIOR, 2009), pontas abrasivas pedra de Arkansas (JUNIOR, 2009; OLIVEIRA, 2006), alicates (IRELAND et al,2004; TAVARES, 2006; OLIVEIRA, 2006; PIGNATTA, 2006; PITHON, 2008) e brocas multilaminadas carbide de tungstênio, consideradas o padrão ouro, quando usadas em baixa e alta rotação (CAMPBELL, 1995; ZARRINIA et al, 1995;TONIAL, 2000; ELIADES et al, 2004; FONSECA, 2004; OLIVEIRA, 2006; PONT et al, 2010).

Mais recentemente, o laser de alta potência passou a ser utilizada em descolagens de brackets cerâmicos, polimerização de resinas durante a colagem de *brackets*, e cogitados para remoção direta da resina remanescente após a descolagem dos *brackets* ortodônticos (ZUPPARDO, 2003).

Para avaliar se uma técnica é danosa ou efetiva quanto à descolagem de *brackets* e remoção da resina remanescente, alguns métodos de avaliação da superfície dentária como a microscopia óptica, microscopia eletrônica de varredura (PINTO, 2001; VANZIN, 2002; PRIETCH, 2005; SHINYA, 2008; CEHRELI, 2011) e perfilometria (ELIADES, 2004; OZER,2010; KARAN,2010; SABATOSKI,2010; ALBUQUERQUE, 2010) já são largamente utilizadas em pesquisas. Neste contexto, a Tomografia por Coerência Óptica (TCO) surge como uma técnica mais recente de diagnóstico - não invasiva e não destrutiva- que fornece imagens seccionadas de estruturas biológicas internas, em tempo real, e com alto poder de resolução espacial (FUJIMOTO, 2003).

As imagens da TCO são obtidas por meio da utilização da luz ao invés de um campo magnético ou radiação x. Baseia-se nas propriedades ópticas (reflexão e retrodifusão) para geração de imagem. A configuração óptica consiste em um interferômetro de Michelson com uma fonte de luz de banda larga de baixa coerência. A luz gerada em um sistema de TCO é dividida em dois ramos: um braço de amostra, que contém o item de interesse e um braço de referência que contém um espelho móvel. A luz refletida do braço de amostra e do braço de referência são então recombinadas e focadas por um espectrômetro, onde qualquer grau de interferência entre as vigas pode ser observado, mas apenas se a luz de ambos os braços tiverem viajado à mesma distância óptica (MONTEIRO, 2011.a).

Diante do exposto, o presente estudo desmembra-se em dois artigos complementares de um mesmo tema que visam validar o método da TCO para avaliação da superfície de esmalte viável. O artigo 1 avalia a técnica da TCO como objeto de caracterização e quantificação da superfície de esmalte após a descolagem de *brackets* ortodônticos, enquanto o artigo 2 avalia a TCO para mensurar a quantidade de resina remanescente sobre o esmalte, ou perda deste tecido, após remoção da resina remanescente. Durante a pesquisa, também foram usadas técnicas de aferição da rugosidade da superfície, microscopia óptica e eletrônica de varredura como critérios para qualificar a superfície gerada pelos métodos sugeridos.

2 Procedimentos Metodológicos

2. PROCEDIMENTOS METODOLÓGICOS

2.1. Tipo de estudo

Realizou-se um estudo experimental do tipo laboratorial *in vitro*.

2.2. Localização do estudo

O presente estudo foi realizado no laboratório de ópticoeletrônica e fotônica do Departamento de física, e no Laboratório e clínica de Dentística da Pós Graduação em Odontologia da UFPE. As imagens em microscópio eletrônico de varredura (MEV) foram realizadas no laboratório de Microscopia do Centro de Tecnologias Estratégicas do Nordeste - CETENE. E as análises rugosimétricas foram realizadas no Laboratório de Tecnologia Mineral (LTM) da UFPE.

2.3. Estudo Piloto

Um estudo piloto foi realizado inicialmente no intuito de definir protocolos, bem como a melhor posição para inclusão dos dentes em resina acrílica, a padronização da técnica de colagem de *brackets*; e calibrar examinadores para avaliação visual das imagens 2D e 3D do OCT.

Neste, foram utilizados doze dentes bovinos, dos quais seis foram submetidos a descolagem com alicate removedor de *bracket* (grupo A) e outros seis, com pistola (grupo B). Após a remoção do *bracket*, três dentes do grupo A tiveram a sua resina remanescente removida com laser e outros 3 com broca carbide de tungstênio + polimento em pasta diamantada com feltro. Enquanto no grupo A, 3 dentes tiveram a sua resina remanescente removida com ponta de fibra de vidro e os outros 3, com broca carbide de tungstênio + polimento com kit de discos de óxido de alumínio.

Os dentes foram avaliados em três momentos: inicial com o esmalte intacto, após a descolagem do *bracket* ortodôntico e após a remoção da resina remanescente proveniente da descolagem do *bracket*. Os aparelhos de avaliação utilizados foram: microscópio óptico (MO), Tomógrafo por Coerência Óptica (TCO) 2D e 3D, e Perfilômetro.

2.4. Métodos

2.4.1. Coleta, desinfecção, seleção e armazenamento dos dentes

No estudo definitivo foram usados 60 dentes bovinos incisivos inferiores (Universidade Federal de Pernambuco, Comitê de Ética Animal, número do protocolo aprovado: 031779/2012-79). Os dentes foram lavados e armazenados em Cloramina T (0,05%) para desinfecção até o início da pesquisa. Após preparo das amostras elas foram armazenadas em ambiente úmido com soro fisiológico durante todo o estudo.

Para a seleção das amostras foi utilizado como critério de exclusão: a existência de trincas no esmalte dental observadas a olho nu e a presença de manchas descalcificadas ou pigmentadas.

2.4.2. Preparo dos espécimes

As raízes foram seccionadas por um disco diamantado, e as coroas incluídas em um molde de matriz metálica (2 x 2 x 2 cm) com resina acrílica (Jet, São Paulo, Brasil).

Com a finalidade de uniformizar a rugosidade das superfícies iniciais, mantendo a curvatura do dente incisivo bovino, as faces vestibulares foram submetidas a uma sequência de acabamento manual com discos de lixa d'água nas granulações 320, 600, 800 e 1200 (3M, Sumaré, SP, Brasil), seguida do polimento com disco de feltro e suspensão aquosa diamantada de 5µ (Buehler, Lake Bluff, IL, U.S.A.).

2.4.3. Procedimentos de colagem e descolagem

Para simular o posicionamento clínico durante a descolagem do *bracket*, utilizou-se uma morsa para fixação individual de cada corpo de prova no encaixe da cabeça da cadeira odontológica (Figura 1).

A profilaxia da superfície do esmalte para prepará-lo para a colagem do *bracket* foi realizada com escova de Robinson (Microdont, Socorro, SP, Brasil), pasta de pedra-pomes extrafina (S.S. White, Rio de Janeiro, Brasil) e água, em baixa-rotação (Fig. 2.a), lavada e secada por tempo igual a 10" cada etapa. Em seguida, foi colada uma fita adesiva vazada, com área interna de 4mm^2 para delimitar a área a ser estudada. Posteriormente foi realizado o condicionamento ácido com gel de ácido fosfórico, por 30” (CONDAC 37%, FGM, Joinville, Brasil) (Fig. 2.b), seguido de lavagem com jato de água intermitente por 30” e secagem com leves jatos de ar comprimido, por 15”.

Figura 1. A) Cadeira odontológica com a morsa mecânica apoiada no encaixe da cabeça da cadeira odontológica simulando a altura do dente do paciente numa situação clínica.

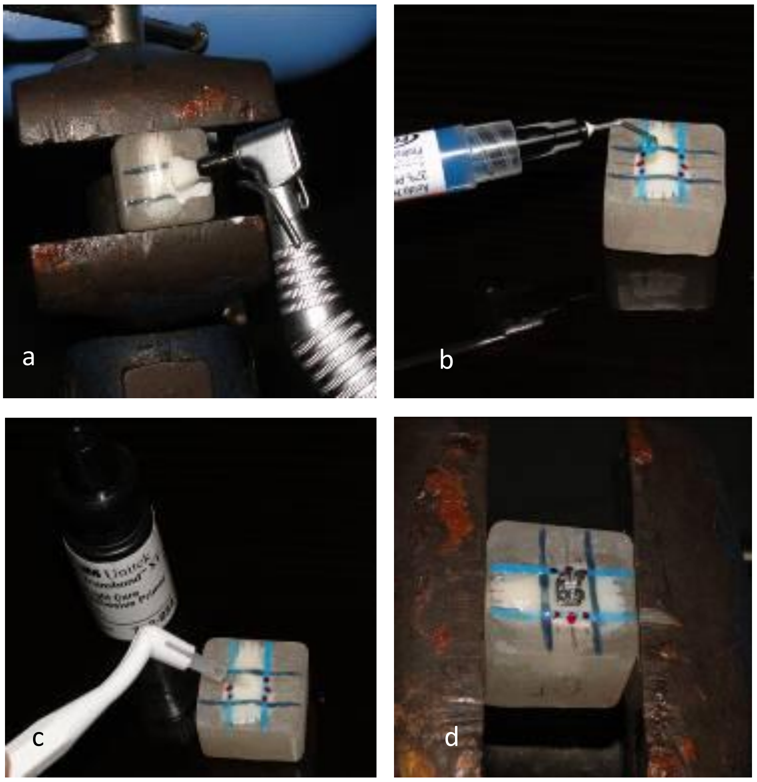

Figura 2. a) Profilaxia com Pedra Pomes e água, b) Condicionamento ácido, c) Aplicação do adesivo, d) *Bracket* colado centralizado no longo eixo da coroa clínica.

No procedimento de colagem dos *brackets*, uma camada fina de TransbondTM XT Adesivo-Primer (3M Unitek, Monrovia, CA, U.S.A.) foi aplicada, na superfície desmineralizada, com micro-aplicadores descartáveis (Fig. 2.c), (Microbrush Corporation, Grafton, WI, U.S.A.) e espalhada com um ligeiro jato de ar isento de umidade. O *bracket* pré-ajustado de aço inoxidável para incisivo central superior direito (Kirium line – AbZIL, São José do Rio Preto, SP, Brasil) foi posicionado centralizado no longo eixo da coroa (Fig. 2.d), e colado com resina ortodôntica TransbondTM XT (3M Unitek), aplicando-se uma pressão mínima com a finalidade de permitir um escoamento semelhante do material em todos os dentes. Após removido o excesso de resina com uma sonda exploradora, a interface *bracket*/esmalte foi polimerizada com o aparelho Radi i Plus (SDI, São Paulo, Brasil) com potência de 1200mw/cm^2 por 10” em cada face, seguindo a orientação do fabricante do material.

3. Divisão dos grupos experimentais

3.1. Artigo 1

O objetivo neste artigo consistiu na avaliação da TCO 2D e 3D como instrumentos de medição do IAR, comparando falhas do descolamento do *bracket* pela pistola 346/Zatty (Iacanga, SP, Brasil) e pelo alicate 346/ICE (Cajamar, SP, Brasil). E quantificar a resina remanescente após a descolagem do *bracket* através da técnica da TCO 2D. Bem como validar o TCO como um instrumento de mensuração do IAR.

Para tal, foi utilizado um total de 20 amostras divididas em dois grupos iguais, sendo um grupo (A) submetido ao método mais convencional, descolados com o alicate de descolagem 346, no qual as pontas ativas do alicate foram posicionadas na interface *bracket*/adesivo e realizado um leve movimento de báscula e tração (Figura 3A e Figura 4a). E o outro grupo (B) com a pistola removedora de *bracket* que dispõe de um dispositivo plástico apoiado na superfície do dente, enquanto um gancho traciona as aletas cervicais dos *brackets* (Figura 3B e Figura 4b).

Figura 3. Pistola removedora de *bracket* 346/Zatty.

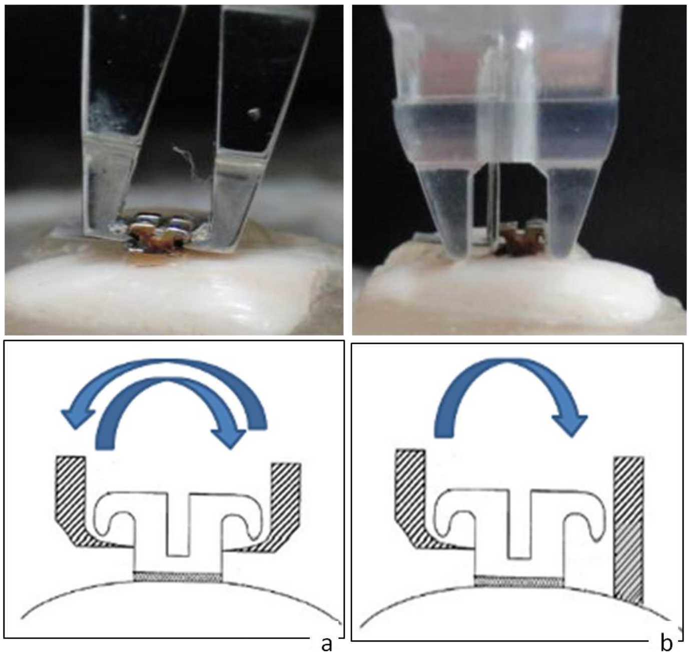

Figura 4. a) Método das aletas- extensões metálicas do alicate foram posicionadas abaixo das aletas do *bracket* no sentido gengivo-oclusal antes de serem pressionadas simultaneamente num movimento de báscula. b) Método da Pistola- uma parte da extensão em forma de gancho foi posicionada abaixo da aleta gengival do *bracket* e a outra parte ficou apoiada na superfície do esmalte antes de ativar a pistola, num movimento de tração unilateral. As setas azuis referem-se ao tipo de movimento realizado pelos instrumentos utilizados para descolagem. Esta é uma imagem modificada de Brosh, 2005.

3.2. Artigo 2

No segundo artigo foi objetivo analisar qualitativa e quantitativamente quatro diferentes métodos de remoção da resina remanescente e polimento após a descolagem do *bracket* ortodôntico, usando a técnica da TCO 2D e do microscópio eletrônico de varredura (MEV). Optou-se então por padronizar a descolagem dos *brackets* com o alicate de descolagem 346, e em seguida 40 amostras de dentes bovinos foram divididas aleatoriamente em 4 grupos (n=10): G1 - broca carbide de tungstênio (BCT) 30 lâminas (Jet Carbide Burs, Ontario, Canadá) em alta rotação com refrigeração de água + pasta diamantada de 3 µ (Diamond, FGM, Joinville, Brasil) e disco de feltro (Diamond); G2- broca de fibra de vidro (TDV, Pomerode, SC, Brasil) em baixa rotação com refrigeração; G3- laser Er:YAG (Fotona Plus, Stuart, EUA) com 100 mJ, 1.00 W e 10 Hz; G4- BCT + discos de óxido de alumínio (Kit Ortho 2.2, DhPro, Paraná, Brasil). A verificação visual da remoção do remanescente adesivo foi realizada por visão direta sob a luz do refletor odontológico e com utilização da ponta ativa arredondada do explorador, simulando a conduta clínica (Figura 5).

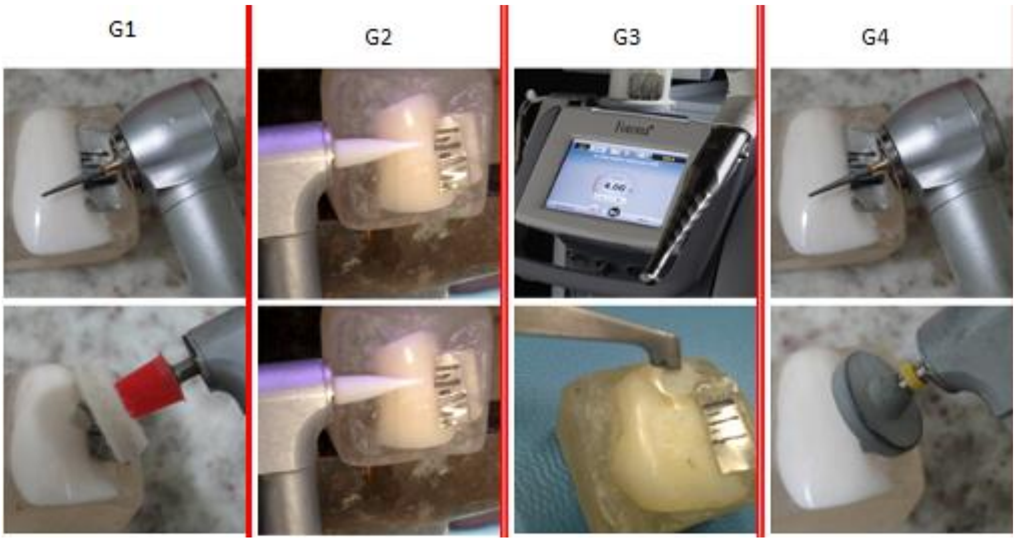

Figura.5. Técnica utilizada para remoção da resina remanescente e polimento, em cada grupo. G1- remoção com BCT + polimento com pasta diamantada com disco de feltro; G2- remoção e polimento com pontas de fibra de vidro; G3- remoção e polimento com laser ER:YAG; G4- remoção com BCT + polimento com disco de óxido de alumínio.

4. Métodos de avaliação

4.1. Avaliação da rugosidade

A superfície de esmalte foi avaliada através do perfilômetro por contato (Mitutoyo SJ-400, Japan). Os espécimes eram colocados sobre uma mesa de medição e realizadas leituras de 1.7 mm nos planos longitudinal e transversal dentro da área central do dente. A sonda de medidas moveu-se em velocidade constante (0.1 mm/s). Cada perfil teve o Ra avaliado, que consiste na média aritmética entre picos e vales.

Figura 6. Imagem aproximada do dente posicionado para aferição da rugosidade através do Perfilômetro

4.2. Microscopia eletrônica de varredura

Uma amostra de cada grupo foi selecionada para representar os grupos estudados. Estes foram metalizados com ouro e colocados para análise em microscópio eletrônico de varredura (FEI, Quanta 200 FEG, Oregon, USA) em aumento de 300 e 5000 vezes. Sempre que surgiram dúvidas a respeito da composição da superfície, a análise no detector de energia dispersiva de raio x (Energy Dispersive X-Ray Detector- EDS) também foi executada.

4.3. Tomografia por Coerência Óptica (TCO)

Foi utilizada uma montagem comercialmente disponível (Spectral Radar SR-OCT:OCP930SR/ Thorlabs, New Jersey, USA) localizado no Centro de Lasers – CLA do Instituto de Pesquisas em Energia Nuclear – IPEN/ USP (Figura 7 e 8). Nesta montagem, a fonte de luz consiste num diodo superluminescente (SLD) com comprimento de onda central de 930nm. Este sistema é composto de três partes principais: uma peça de mão (scanning probe), uma unidade base e um computador. A unidade base contém fonte de luz (SLD). Um adaptador de fibra ótica é utilizado para direcionar a luz do SLD ao interferômetro de Michelson, que se encontra localizado no interior da peça de mão (scanning probe). A luz refletida pela sonda e pelo espelho de referência é recombinada através de uma mesma fibra ótica até o espectrômetro e sensor de imagem localizado na unidade base. Esta unidade, apresenta-se conectada a um computador o qual é equipado com 2 cartões de aquisição de dados de alta performance. Toda a aquisição de dados assim como os processamentos necessários é realizada via software específico. A maior profundidade deste sistema é de 1.6 mm e em largura é de 6.0 mm, com uma resolução axial de 6.2 µm. (MONTEIRO, 2011b)

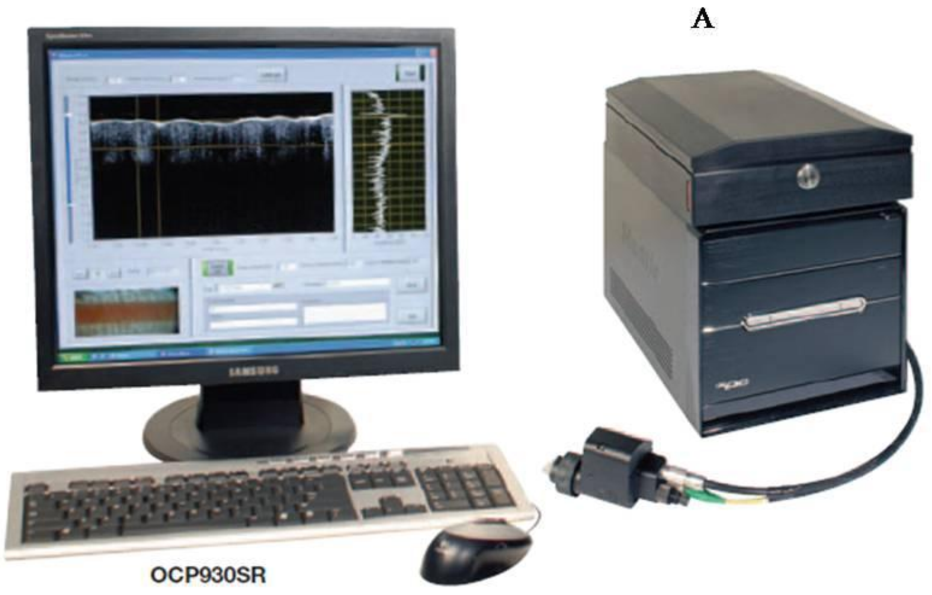

Figura 7. (A) SR-OCT: OCP930SR (Thorlabs New Jersey, USA).

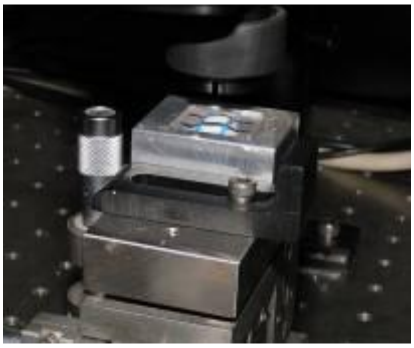

Figura 8. Imagem aproximada do dente acoplado a matriz metálica para aferição de medidas em TCO.

Para aferições quantitativas apuradas através do TCO, foi necessário saber o índice de refração dos materiais que foram estudados. Então, o índice de refração de todos os materiais testados foi calculado. Amostras dos materiais foram obtidas usando um molde de teflon então a exata espessura do material pode ser determinada usando um compasso digital (0.01 mm). Após obter imagens em TCO, o índice de refração pode ser determinado aplicando a formula= distância óptica/ distância real (MONTEIRO, 2011a). Em posse destes dados, cada imagem pode ser submetida para uma analise comparativa através do software Image J bem como a espessura da camada de resina da resina remanescente, mensurada. As imagens geradas (inicial e final) foram sobrepostas permitindo esta análise quantitativa. Adicionalmente, também foram realizadas imagens em todos os momentos da pesquisa em TCO 3D.

4.4. Microscópio Óptico

Para uma análise complementar, imagens foram capturadas de cada amostra para obter propriedades comparativas de luz branca refletida. Efeitos macroscópicos foram capturados por um microscópio óptico (MO -0.65x), tornando possíveis medições de resina remanescente para ser comparada com imagens em TCO 3D.

4.5. Análise Estatística

Os resultados foram submetidos a testes estatísticos (Mann-Whitney e Wilcoxon Signed Ranks Test). As análises foram feitas com os valores da rugosidade usando o SPSS software 13.0 (Statistical Package for the Social Sciences, Chicago, USA). As médias e desvios padrão foram calculados, e as distribuições normais foram testadas através do teste de Kolmogorov–Smirnov test. One-way ANOVA foi calculado para checar a existência de alguma diferença entre os grupos, e em caso de diferença estatisticamente significante, o teste de Mann Whitney foi aplicado. Comparações entre as médias dos valores de Ra para cada grupo nos dois momentos avaliados (inicial e final) foi feito através do teste de Wilcoxon signed-rank. A significância estatística para todos os testes foi considerada com $p < 0.05$.

4.6. Análises e Teste de Kappa

Três avaliadores, previamente calibrados, avaliaram cada espécime após descolagem dos *brackets* através do alicate e da pistola, por uma apresentação imagens de slides em tela de computador de 15 polegadas que dispunham aleatoriamente as imagens em MO e em TCO 3D (Fig. 9). Para quantificar a quantidade de resina remanescente, foi utilizado o Índice de Adesivo Remanescente (IAR), postuladas por Artun and Bergland (1984).

Os códigos do IAR 0, 1, 2 e 3 significam: (0) nenhum adesivo ficou na superfície do dente, implicando que a fratura de união ocorreu na interface resina/esmalte; (1) menos da metade do adesivo ficou sobre a superfície do dente, implicando que a fratura de união ocorreu predominantemente na interface resina/esmalte; (2) mais da metade do adesivo ficou sobre a superfície do esmalte, implicando que a fratura de união ocorreu predominantemente na interface *bracket*/resina; (3) todo o adesivo restou sobre a superfície do esmalte deixando a impressão da base do *bracket*, implicando numa fratura de união na interface *bracket*/resina.

A reprodutibilidade de cada técnica ótica foi avaliada pela estatística Kappa para quantificar o nível de concordância entre os avaliadores das imagens em MO e em TCO.

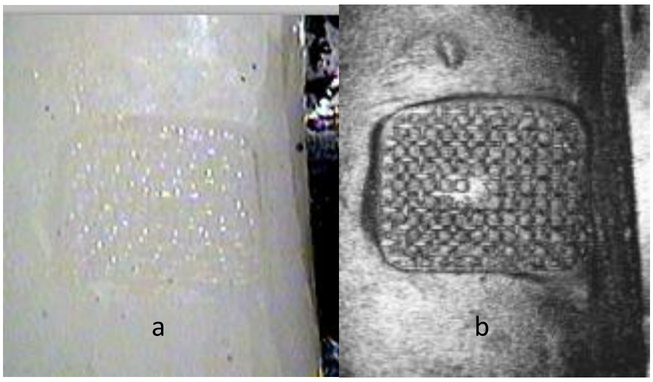

Figura 9. a) Imagem em microscópio óptico (0.65x), b) Imagem em Tomógrafo por Coerência Óptica.

5. Métodos de avaliação utilizados em cada artigo

5.1. Artigo 1

Para comparar quantitativamente a superfície do esmalte e a resina residual após a descolagem do *bracket*, utilizou-se o Índice de Adesivo Remanescente de Artun e Bergland (1984). As imagens foram obtidas a partir de Microscópio Óptico e da Tomografia por Coerência Óptica 3D. Após classificar as imagens de acordo com os *scores* sugeridos no IAR, os resultados dos avaliadores foram submetidos à análise estatística de Kappa.

Para quantificar a resina remanescente após a descolagem do *bracket* ortodôntico, foram utilizadas imagens 2D por TCO. Os métodos utilizados serviram para validar o TCO como um método de mensuração do IAR.

5.2. Artigo 2

Para comparar quantitativamente os métodos de remoção da resina remanescente e polimento da superfície, fez-se necessária análise das amostras previamente a qualquer intervenção e após cada etapa realizada no estudo. Dessa forma, as amostras foram analisadas, antes e depois, quanto a rugosidade superficial da estrutura remanescente através do Perfilômetro.

Para qualificar a superfície de esmalte e quantificar a perda de esmalte e excessos de resina foram utilizadas imagens em TCO 2D e 3D. Este último com a finalidade apenas de qualificar a superfície. Imagens em MEV também foram usadas para qualificar a superfície do esmalte após os procedimentos.

O uso do TCO teve como objetivo validar o seu uso para mensurar se houve perda de esmalte ou excesso de resina após a remoção da resina remanescente com 4 diferentes métodos de remoção.

3 Artigo 1

Manuscript formatted according to the Angle Orthodontics Journal norms.

An alternative method to assess remnant adhesive on enamel: Optical Coherence Tomography

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Abstract

<u>Objective:</u> this study aimed to assess *En-face* Optical Coherence Tomography (3D OCT) and Optical Microscopy (OM) as an instrument to measure the Adhesive Remnant Index (ARI), compare the failures derived from two different methods of bracket debonding, and quantify remnant adhesive through *Axial sections images* (2D OCT). <u>Material and methods:</u> Twenty bovine teeth was divided into 2 groups (*n=10*) according to brackets debonding method: A, debonding plier 346 (*ICE*) and B, lift-off debonding instrument 346 (*Zatty*). Remnant adhesives were quantified by 3 evaluators through OM (0.65x) and 3D OCT images; and remnant adhesive thickness and validation of fracture propagation were evaluated by 2D OCT images, and measured by ImageJ software. <u>Results</u>: OM and 3D OCT showed 0.83% and 0.70% of agreement in a Kappa statistic test, respectively. The thickness mean of remnant adhesive left by bracket debonding was 164µm (±34 µm). ARI results showed 72,7% *score 3* and 27,3% *score 2* in group A; and 55,6% *score 1*, 33,3% *score 2* and 11,1% *score 3* in group B. <u>Conclusion</u>: MO and 3D OCT were considered satisfactory to measure ARI. 2D OCT was precisely to measure thickness of remnant adhesive or enamel loss. Bracket debonding by plier has bond fracture predominantly at bracket/adhesive interface which preserves more enamel structure than debonding by lift-off instrument where bond fracture occurred mostly at enamel/adhesive interface. All methods used to assess enamel surface, each with its own characteristics, were considered good for assess enamel surface. However, among the methods studied, OCT has the possibility of being applied clinically.

Key- words: Dental Debonding; Optical Coherence Tomography; Orthodontic Brackets.

INTRODUCTION

Orthodontic bracket debonding is a subject that requires attention for orthodontists professionals, once this phase can promote permanent damages on enamel external layer.[1,2] Debonding procedures occurs, generally, at the end of treatment, but can also occur when bracket repositioning is required. [3]

Some factors can influence on failures of brackets removal, as type of enamel conditioning agents (phosphoric acid, self-etching primers, polyacrylic acid), [4] adhesive resin, cement and polymerization methods. [5, 6] Moreover mechanical factors as bracket design,[7] architecture base of bracket, [3,5,6] debonding instruments and the way of pick up on these instruments influence on intensity of debonding forces. [3]

Several instruments for bracket debonding have been evaluated about the impact effects on enamel surface.[8, 9] These effects influenced by force vectors can be assessed using qualitatively analyses of remnant adhesive. Bracket remover, weingart and ligature cutter pliers with similar bilateral movement of forces vectors showed satisfactory effects. [8,10] Although lift-off instruments, that are indicated for patients with high sensibility or severe periodontitis diseases, present unilateral force vectors. [11]

The Adhesive Remnant Index (ARI) is a parameter used to evaluate the residual adhesive remaining on a tooth or bracket after debonding.[12, 13, 14] As a qualitative and subjective scoring system initially classified through visual observation and optical microscopy (OM), this system has been adapted to more precise techniques, including scanning electron microscope (SEM), finite element analysis, and three-dimensional profilometry.[15-17]

In the past years, Optical Coherence Tomography (OCT) - as a non invasive and non destructive - has been used to improve evaluation methods. This optical imaging modality provides real-time, 1D depth, 2D cross-sectional, and 3D volumetric images with micron-level resolution and millimeters of imaging depth. OCT images also allow structural observation of samples, based on light backscattered from different layers of material within the sample.[18, 19]

The purpose of this study was to assess the OCT to measure changes on tooth surfaces and validate *En-face* images as an instrument to measure the Adhesive Remnant Index [20] comparing with OM images. Therefore, two debonding methods were used: a debonding plier 346 (ICE, Cajamar, SP, Brazil), and a debonding lift-off instrument 346 (Zatty, Iacanga, SP, Brazil).

MATERIALS AND METHODS

Sample selection and preparation

Bovine lower incisors were used in this study after submission to Animal Ethics Committee (Universidade Federal de Pernambuco, protocol approval n. 031779/2012-79). Twenty bovine incisors were selected by visual observation, excluding teeth with cracks, fractures, grooves or decalcification. The specimens were stored for a week in Cloramine T (0,05%) for disinfection and then kept in a humid environment during the experimental stages.

After root sectioning, the lingual side of the teeth was inserted in acrylic resin using a metallic square frame (2 × 2 × 2 cm). Teeth surface was carefully polished with sandpaper of decreasing grit (320, 600, 800 and 1200), taking care to avoid planing the buccal surface, leaving its natural convexity, and final polishing was performed with a felt disk and diamond suspension in water (5 µm) (Buehler, Lake Bluff, IL, USA). A metallic metal strip (matrix band) was fixed beside each tooth to serve as a reference during OCT image acquisition.

Bonding procedures

For the bracket bonding procedure, the teeth were pumiced and a bonding area of 4 mm^2, carefully centralized along the long axis of the crown, was outlined with adhesive tape. The enamel surface was etched with 37% phosphoric acid, to which one layer of Transbond^{TM} XT Adhesive-Primer (3M Unitek, Monrovia, CA, USA) was applied. Photoactivation were proceeded following the manufacturer's instructions with a LED light (Radii Cal, SDI, São Paulo, SP, Brazil) with irradiance of 1200 mW/cm^2 for 20 s.

Preadjusted stainless steel brackets for the right upper central incisor (Kirium Line – AbZIL, São José do Rio Preto, SP, Brazil) were positioned and bonded with Transbond^{TM} XT orthodontic resin (3M Unitek). During this step, sufficient pressure was applied to allow uniform flow of the adhesive resin through the bracket. All excesses were removed with an exploratory probe, and the interface bracket/adhesive was then photoactivated on each side of the bracket for 10 s - 1200mW/cm^2. The teeth were then stored in a humid environment, and so it remained throughout the experiment.

Debonding procedure and experimental group division

After 7 days, specimens were randomly divided into 2 groups (n=10), according to the method of bracket debonding: A- debonding plier 346 (ICE, Cajamar, SP, Brazil), and B- lift-off bedonding instrument 346 (Zatty, Iacanga, SP, Brazil). Aimed to promote better clinical simulation forces vectors during debonding procedures, each sample was positioned with a bench vise that was fixed to a dental chair neck. Debonding procedure followed manufacturer’s instructions.

For plier debonding method, its metal extensions were placed at the outer wings of the bracket [3] that were squeezed together in a bilateral torsion movement producing a tensile bond failure perpendicular to the tooth surface. This method is known as the wings method[14] (Figure 1a). For lift-off instrument method, it was positioned by linking its hanger to the upper left bracket wing and simultaneously resting the instrument on the tooth. Compression of the pliers caused the bracket to lift off on application of a pulling force [21] (Figure 1b). In both bonding and debonding procedures only one operator carried out all clinical procedures.

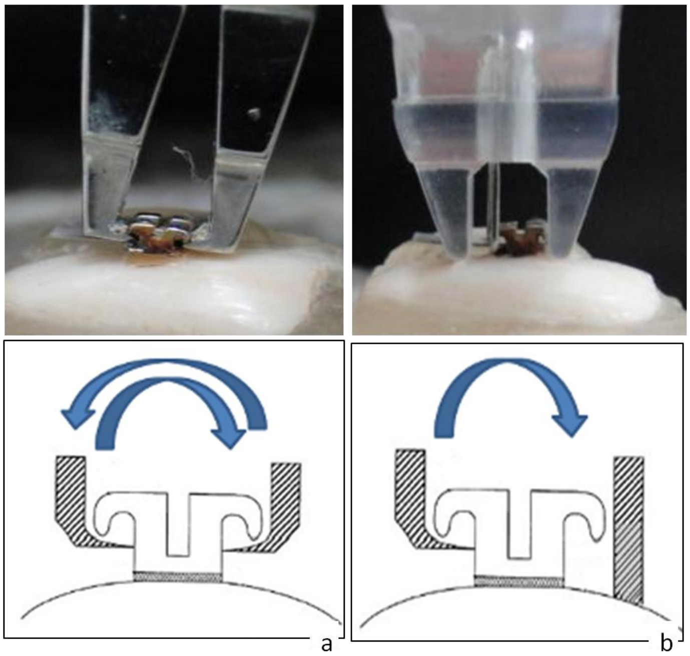

Figure 1. Debonding methods. a) Wings Method- metal extensions at the outer wings of bracket in a bilateral torsion movement (double arrows). b) Lift-off Instrument Method- the hook extension seated under the gingival bracket wing; while metal extension is supported on the enamel surface before activating the instrument in an unilateral movement. There is an image modified from Brosh, 2005.

Enamel Surface Evaluation

OCT

Two commercially available OCT systems were used for *en-face* (3D) and *axial sectional* (2D) image acquisition (Ganymed Spectral Radar SR-OCT: OCP930SR/ and Callisto Spectral Radar SR-OCT: OCP930SR Thorlabs, New Jersey, USA, respectively). Both systems operate with a super-luminescent diode (SLD) light source 930nm central wavelength. These systems comprise three main parts: a handheld scanning probe, a base unit, and a personal computer (PC) (Fig. 2). The base unit contains the SLD light source. A fiber optic coupler is used to direct the light from a broadband SLD source to the Michelson interferometer, which is located inside the handheld probe. Both probe and reference light travel back through the same fiber to the spectrometer and imaging sensor located in the base unit.

The base unit is connected to the PC, which is equipped with two high-performance data acquisition cards. All required data acquisition and processing is performed via the integrated software package, which contains a complete set of functions for controlling data measurement, collection and processing, and for displaying and managing OCT image files.[18] The *en-face* images were acquired as a view of 8 x 8 mm, and a resolution of < 5.8 µm, to be analyzed through ARI.

Through *axial* optical tomographic images, accurate quantitative of remnant adhesive were done by thickness measurements. Although, the refractive index of adhesive and resin influence on light depth measurements and should be calculated. Reference samples of adhesive thickness were measured using a digital calipter and OCT images; and refractive index could be determined by applying the formula: refractive index = optical distance/real distance. [22]

OM

As a complementary analysis, images were captured from each sample to achieve comparative properties of reflected white visible light. Macroscopic effects were captured by an Optical Microscope (OM -0.65x), making possible remnant adhesive measurement to be compared to OCT 3D images.

Data Analyses

Three evaluators, previously calibrated, analyzed each specimen after brackets debonding by optical microscope images and 3D OCT images, plotted randomly in a slide presentation in a 15” screen size computer. To quantify results, an adhesive remnant index (ARI), postulated by Artun and Bergland (1984), [23] was used considering the two debonding methods.

The ARI code 0, 1, 2 and 3 means: (0) no adhesive left on the tooth surface, implying that bond fracture occurred at adhesive/enamel interface; (1) less than half of adhesive is left on the tooth surface, implying that bond fracture occurred predominantly at adhesive/enamel interface; (2) more than half of adhesive is left on the tooth surface, implying that bond fracture occurred predominantly at bracket/adhesive interface; and (3) all adhesive is left on tooth surface with a distinct impression of the bracket base, implying that bond fracture occurred at bracket/adhesive interface.

Also mode of failure was analyzed considering uncoated versus precoated metal bracket base surface images. For the uncoated brackets, bond failures occurred at the bracket-adhesive interface. For precoated brackets, bond failures occurred at the enamel-adhesive interface, and partially coated refer to mixed failure. [24-26]

The reproducibility of each optical technique was assessed using Kappa statistics to quantify the level of agreement between the two evaluators through microscope and OCT images.

RESULTS

Examples of remnant adhesive were viewed using two modalities: OM (0.65x) and *en-face* OCT images. Figure 2a is an example of remnant adhesive by OM and figure 2b shows *en-face* images. A demarcated boundary of adhesive remnant was shown with better contrast in OCT images. However, there was observed lower agreement (70%) in Kappa statistic test to OCT images, against 83% to OM images.

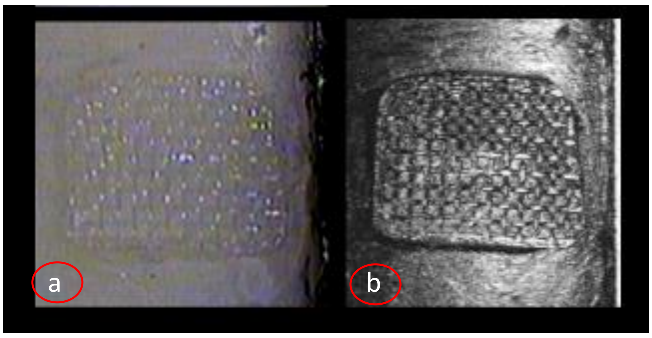

Figure 2. Adhesive remnant in OM (a) and *en-face* OCT images (b).

According to ARI results, in group A 72,7% presented all adhesive left on the tooth surface with a distinct impression of the bracket base (score 3), and 27,3% left more than half the adhesive on the tooth surface (score 2). While in group B, 55,6% presented less than half the adhesive is left on the tooth surface (score 1), 33,3% found score 2, and 11,1%, score 3. None of the groups presented all adhesive removed (score 0). Considering the samples there was noted a difference in distribution of groups A and B, which is shown in table 1.

Table I. Distribution of sample appeared in each score of adhesive remnant index (ARI) between group A and B

	Group A (Plier)	Group B (Lift-off instrument)
Score 3	8	1
Score 2	2	3
Score 1	0	6
Score 0	0	0

After an analysis with optical microscopy of metal brackets bases it was possible to note the mode of failure in each group. In group A there was a prevalence bracket/adhesive interface failure. On the other hand, group B showed a prevalence of mixed fracture, and score 1.(Table I and II)

Table II. Distribution of metal brackets' failure mode between samples of groups A and B.

Group	Enamel/adhesive	Mixed	Bracket/adhesive
A	0	1	9
B	0	7	3

Beyond *en-face* OCT image, *axial* tomographic image allows evaluate *adhesive*/enamel interface and measure remnant adhesive thickness. A white line under remnant adhesive (figure 3b) was observed in 80% of lift-off instrument samples, and in none of plier group samples. Through set up of images scales by ImageJ and index refraction, a mean about 164 µm (± 34 µm) was observed considering both groups (Figure 3c).

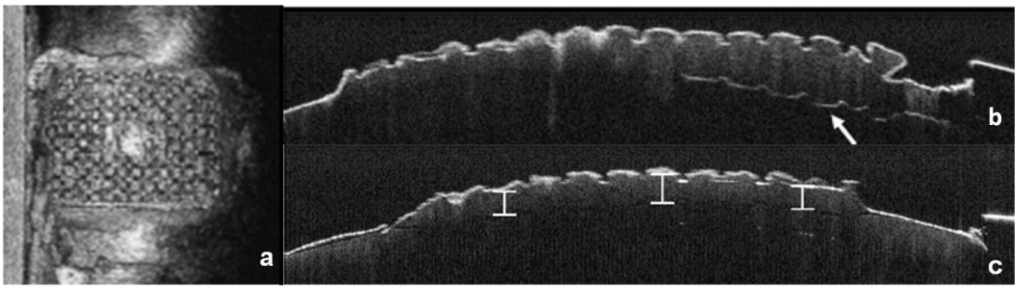

Figure 3. a) *En- face* image; b) *Axial sections OCT images*: white line under remnant adhesive (arrow); c) Remnant adhesive left after bracket debonding, showing the irregular surface with the distinct impression of a bracket base (arrows).

DISCUSSION

As the human teeth, the bovine teeth could be used for researches. [27, 28] For this present study, bovine lower incisors were used as a substitute to human premolars. Besides the similarities between both enamel substrates, bovine incisors were also chosen because of the less convex buccal area, favoring OCT image acquirement.

A lot of studies have been used the Adhesive Remnant Index [2, 7, 9, 10, 17, 23, 24, 29, 30] to measure amount of adhesive left on enamel surface after bracket debonding through visual observation. In the present study OM and *en-face* images were tested to classify the ARI. And even observing better contrast on *En-face* images, OM was considered very good while *en-face* images, just good. Then, the lack of familiarity of the evaluators with these 3D images can suggest the better results of OM imagens on Kappa test.

In this study it was possible to infer that debonding technique is directly related to remnant adhesive.[7] Debonding method of plier uses a bilateral force at bracket/adhesive interface that transferred the least amount of stress to the enamel [2, 8, 31-35] and permits the movement control. However, lift-off debonding method uses the unilateral movement that became difficult to control it, being as pure tensile force.

It would be expected that significant differences in debonding techniques will result with different ARI *scores*, [8] what was reached in the present study. The predominance of *score 3* (72.7%) in samples debonded by plier was equivalent to *score 1* (55.6%) in samples debonded by lift-off instrument. Although, another study had showed no differences in ARI *scores*. [11] The small amount of adhesive left on enamel surface can be consequence of a unilateral movement.

Considering controversial the place to support the pliers' metal extensions, other study defends that independently if its extensions will be placed on bracket bases or wings, there are force transmissions to bracket/adhesive/enamel interface. However, on wing method, because of the fact that extensions are positioned away from the interface, the force applied required decreases to do the procedure. [14]

The structural deformation of the metallic bracket frequently occurred during wing method by plier, [21] and it was expected that its deformation would result with more detachment at the bracket/adhesive interface, [13] leading to high ARI scores what was reached on plier group. The equivalent force system generated by the lift-off instrument is a pull-off force perpendicular to the bracket base, which creates a moment that is parallel to the enamel surface. There was no compression of the bracket, and although there was a pulling force insertion at one bracket wing, all brackets debonded with the lift-off debonding instrument remained intact afterward. [21]

On the other hand, lift-off debonding instrument allows a predominant failure at enamel/adhesive interface which offer more damage risks to enamel structure than debonding by plier[2, 8, 31-35] once the strength (complete polymerization) of the adhesive material was initially weaker at the bracket/adhesive than at the enamel/adhesive interface, as light-cured, what might benefit *scores 3*.[14] Only a small group of studies seems to defend adhesive/enamel interface fracture, because it is faster and easier to remove remnant adhesive, [2, 29, 36, 31, 8, 32, 33] but not necessarily safer.

In the present study, the OCT became as a non-destructive method of section analysis to validate the debonding failure mode more precisely and with better resolution. These characteristics could be seen in the white line under the remnant adhesive, representing a site of a crack between tooth and adhesive. Crack initiation is a phase in fatigue-life of a crack that is considered more difficult to predict, since it can depend on microstructural properties. The length of actual initiation period is strongly affected by local microstructural features that may cause localized stress concentrations, such as surface scratches, micro-cracks, particle–adhesive, etc. [19]

Considering this, preliminary studies indicated that that OCT is potentially a powerful technique for visualizing all steps of crack propagation. It is also an important technique for selection of specimens, helping to reject samples with small details on enamel surface, [19] as micro-cracks, porosities, filler particles, crazes, and crack initiation, what open up the prospect of selection of specimens prior to fatigue studies.

Mode of failure was classified by OM images of bracket base, but through OCT sections images it is possible to understand more about fracture. In the example of figure 3a, mode of failure was classified as adhesive/bracket interface, but the same sample analyzed by *axial section* OCT images it is possible to observe a partial adhesive-enamel failure represented as a gap (white line under remnant adhesive- figure 3b). This gap between adhesive and enamel was observed only on samples of debonding by lift-off instrument that present 80% of adhesive failure as a mixed fracture.

The *Axial section* images could measured the mean (±SD) thickness for the groups as 164 µm (± 34 µm), which is similar to the results of another study, [37] which found 102.7 µm (± 79.71 µm) for resin-coated adhesive pre-coated brackets. Clinically, the amount of adhesive between bracket and enamel surface should be minimal and totally uniform, because irregularities can predict different loads in mesio-distal or cervical-incisal axis, and change tooth prescription.

In this context, the OCT system can be clinically applied in anterior teeth to analyze remnant adhesive, before rebonding the bracket, to check if the wrong directions observed by tooth position were a consequence of adhesive thickness failure or an incorrect X position. Moreover, OCT 3D can be applied on real time to establish the correct position of the orthodontic bracket and improve treatment quality.

CONCLUSIONS

The evidence presented in the present study suggests that enamel evaluation by the OM and *En-face* images methods were considered satisfactory to evaluate the adhesive remnant index.

Both debonding techniques used to remove the metal brackets were effective, but, debonding by plier generally has the bond fracture predominantly at bracket/adhesive interface which preserves the enamel structure more than debonding by lift-off instrument.

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4 Artigo 2

Manuscript formatted according to the Operative Dentistry.

The use of Optical Coherence Tomography as an alternative for enamel surface analysis after bracket debonding

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Abstract

Introduction: This study aimed to evaluate the enamel surface after orthodontic bracket debonding and four remnant resin removal techniques using optical coherence tomography (OCT), scanning electron microscopy, and surface roughness. **Methods**: Forty bovine teeth were divided into 4 groups (n=10) according to the clean-up and polishing methods: G1, 30-blade tungsten carbide bur at high speed + diamond paste and felt; G2, fiberglass/TDV points at low speed; G3, Er:YAG laser 100 mJ/1.00 W; G4, 30-blade tungsten carbide bur at high speed + aluminum oxide polishing system/Dhpro. **Results:** G1, G3 e G4 had similar final roughness, different from G2 that presented a significant increase ($p<0.05$). Surface analysis, showed horizontal and vertical scratches for G1 and G4, punctual areas of mineral loss in G3. **Conclusion:** Clean-up of the enamel surface after bracket debonding directly influences surface roughness. No clean-up method was considered perfect. The Er:YAG laser produced the highest enamel loss. And the use of fiberglass was not capable of adequately polishing, increasing final enamel surface roughness. All three methods used to assess enamel surface integrity, each with its own characteristics, were considered good for measuring enamel loss. However, among the methods studied, OCT has the possibility of being applied clinically.

Enamel aesthetics after orthodontic bracket debonding and subsequent removal of remnant resin has been extensively studied in recent years. The high risk of permanent damage to the enamel structure makes this phase extremely important to maintain the integrity of the enamel surface.[1]

When direct bonding procedures are used for bracket fixation, enamel loss can occur at all stages, from bonding (the use of phosphoric acid) to debonding and during the clean-up procedures.[1–6] However, although the thickness of enamel varies from 1500 to 2000 µm, the first 20 µm has the highest mineral and fluoride content offering high enamel protection, and therefore must be preserved to the maximum.[4–8]

Bracket debonding and removal of remnant resin are extremely important because of the direct influence on the enamel surface. Once scratched, the enamel does not recover its natural aspect.[9] Many instruments have been proposed for bracket debonding and subsequent enamel clean-up, such as Arkansas points, diamond points, multiblade burs, pliers, and others. However, because none of these instruments can achieve complete removal of resin without affecting the enamel surface, several protocols have been proposed.[1,10] Instruments and protocols must be developed and tested with the aim of avoiding possible iatrogenic damage to the enamel structure, leaving it as close as possible to its pretreatment condition.[4,8,11–13]

With regard to enamel clean-up, the carbide tungsten bur can be considered the gold standard according to the published data.[1,5,11,12] This can be attributed to the small amount of surface damage, the short time needed for its application, and the cost-benefit relationship. However, there are now several new instruments for this purpose, such as fiberglass points[8] and laser Er:YAG.[6,9,14,15] The latter is a new innovation in postorthodontic treatment and is considered a promising method because of the possibility of restoring the smoothness of the enamel surface.

Differences in surface roughness can be defined as the set of irregularities (ie, small protrusions and recesses) that characterize a surface.[6] These irregularities are closely related to the brightness of the surface, the reflection of light, and retention of the dental biofilm.[16] However, the roughness of a tooth is influenced by the evaluated direction. The mean human enamel roughness is estimated to be 0.42 μm for the longitudinal (cervico-incisal [CI]) direction, which is flatter than the transverse (mesio-distal [MD]) direction.[1] The importance of surface characterization, especially roughness, is due to the fact that it can influence some clinical procedures, such as bonding, debonding, and maintenance after treatment.

Many methods have been used to assess the enamel surface after bracket debonding and removal of remnant resin, such as visual and tactile observation, contact/noncontact perfilometry, optical microscopy, and scanning electron microscopy (SEM). In recent years, enamel surface loss has been evaluated using optical coherence tomography (OCT), an imaging technique that uses the properties of light and its interaction with biological tissues to generate images of human body parts.[17,18] Like ultrasonography, OCT works at high resolution and in real time. Thus, OCT can be used to evaluate the enamel surface after orthodontic treatment.[19]

Optical tomography has become a powerful method for image acquisition of internal structures of biological systems and materials by obtaining subsurface images in a noninvasive way using light rather than a magnetic field or X-radiation. OCT uses optical properties (reflection and backscattering) for image generation. The optical set-up consists of a Michelson interferometer with a low coherence broadband light source.

The light generated in an OCT system is split into two arms: a sample arm, containing the item of interest, and a reference arm that contains a movable mirror. The reflected light from the sample arm and from the reference arm are then recombined and focused by a spectrometer, where any degree of interference between the beams can be observed, but only if light from both arms has traveled the same optical distance. The intensity of the interference depends on the scattering caused by changes in the structure of the tooth, for example.[20]

Therefore, the purpose of the present study was to perform an in vitro evaluation of the enamel surface after bracket debonding and removal of remnant resin using four different methods of observation: contact perfilometry (roughness analysis), OCT, and SEM. Two null hypotheses were tested: (1) there are no differences between the methods used for removal of remnant resin; (2) there are no differences between the observation methods.

MATERIALS AND METHODS

Sample selection and specimen preparation

Bovine lower incisors were used in this study (Universidade Federal de Pernambuco, Animal Ethics Committee protocol approval n. 031779/2012-79). All teeth were kept in 0.05% Chloramine T for 1 week for disinfection and then kept in a humid environment during the experimental stages. The selection criteria included the absence of cracks, fractures, grooves or surface decalcification under visual observation in natural light (n=40).

After root sectioning, the lingual side of the teeth was inserted in acrylic resin using a metallic square frame (2 × 2 × 2 cm). A metallic metal strip (matrix band) was fixed beside each tooth to serve as a reference during OCT image acquisition. The surface of the teeth was carefully polished with sandpaper of decreasing grit (320, 600, 800 and 1200), taking care to avoid planing the buccal surface, leaving its natural convexity. Final polishing was performed with a felt disk and diamond suspension in water (5 µm) (Buehler, Lake Bluff, IL, USA).

Bonding procedures

For the bracket bonding procedure, the teeth were pumiced and a bonding area of 4 mm^2, carefully centralized along the long axis of the crown, was outlined with adhesive tape. The enamel surface was etched with 37% phosphoric acid, to which one layer of Transbond™ XT Adhesive-Primer (3M Unitek, Monrovia, CA, USA) was applied. Photoactivation were proceeded following the manufacturer's instructions with a LED light (Radii Cal, SDI, São Paulo, SP, Brazil) with irradiance of 1200 mW/cm^2 for 20 s.

Preadjusted stainless steel brackets for the right upper central incisor (Kirium Line – AbZIL, São José do Rio Preto, SP, Brazil) were positioned and bonded with Transbond™ XT orthodontic resin (3M Unitek). During this step, minimal pressure was applied to allow uniform flow of the cement through the bracket. All excesses were removed with an exploratory probe, and the interface bracket/adhesive was then photoactivated on each side of the bracket for 10 s - 1200mW/cm^2. The teeth were then stored in a humid environment, and so it remained throughout the experiment.

Debonding procedures and experimental groups

After 7 days, the brackets were debonded using pliers (no. 346; ICE, Cajamar, SP, Brazil). The metal extensions of the pliers were placed under the bracket wings at the occusal and gingival aspects before the handles were pressed together, which produced tensile bond failure perpendicular to the tooth surface. The teeth were then randomly divided into 4 groups (*n*=10) according to the method of removal of remnant resin (Table I).

Table I. Clinical procedures and composition of materials

Clinical procedures	Material	Composition	Mode
Resin Removal	G1: 30-bladed tungsten carbide bur (Jet)	Tungsten carbide and stainless steel	High speed/ Water cooling MD direction
	G2: Fiberglass (TDV)	Epoxy resin and fiberglass	Low speed/ Water cooling MD direction
	G3: Laser Er:YAG (Fotona Plus)	-	100 mJ/1.00 W/10 Hz. Water cooling on remnant resin, which was then removed by the aid of an exploratory probe
	G4: 30-bladed tungsten carbide bur (Jet)	Tungsten carbide and stainless steel	High speed/ Water cooling MD direction
Final Polishing	G1: 3µm diamond paste and felt disk Diamond (FGM)	Micronized diamond, lubricant base, thickener and emulsifier	Low speed/ Water cooling
	G2: Fiberglass	Epoxy resin and fiberglass	Low speed/ Water cooling
	G3: Laser Er:YAG (Fotona Plus)	-	-
	G4: aluminum oxide kit ortho 2.2 (Dhpro)	Aluminum oxide and silicon carbide	Low speed/ Air cooling

Group 1 (G1) is the most commonly used protocol for removal and polishing; group 2 (G2) is a new method for removing remnant adhesive in which it is possible to finish and polish the enamel surface in one step; in group 3 (G3), no final polishing procedure was applied based on previously published data[14]; and for G4, removal of remnant adhesive was completed as for G1, but using a different polishing procedure.

During these procedures, clinical inspection of the enamel surface was performed by direct visual analysis with the aid of an exploratory probe with a blunt tip under reflected light.

Enamel surface evaluation

OCT

Two commercially available OCT systems were used for image acquisition: Spectral Radar SR-OCT (OCP930SR) and Ganymede Spectral Domain SD-OCT (Thorlabs, New Jersey, USA), respectively. Both systems operate with a superluminescent diode (SLD) light source with 930 nm central wavelength. These systems comprise three main parts: a handheld scanning probe, a base unit, and a personal computer (PC) (Fig 1). The base unit contains the SLD light source. A fiberoptic coupler is used to direct the light from a broadband SLD source to the Michelson interferometer, which is located inside the handheld probe. Both probe and reference light travel back through the same fiber to the spectrometer and the imaging sensor located in the base unit. The base unit is connected to the PC, which is equipped with two high-performance data acquisition cards. All data acquisition and processing is performed via the integrated software package, which contains a complete set of functions for controlling data measurement, collection, and processing, and for displaying and managing OCT image files.[21] The maximum image depth is 1.6 mm and transverse scanning is 8.0 mm with an axial and lateral resolution of less than 7.0 µm and 8.0 µm, respectively. Axial sections images of 7 mm were captured by SR-OCT before and after all procedures, and *en-face* images was captured by SD-OCT, scanning an area of 36mm^2 over the enamel surface.

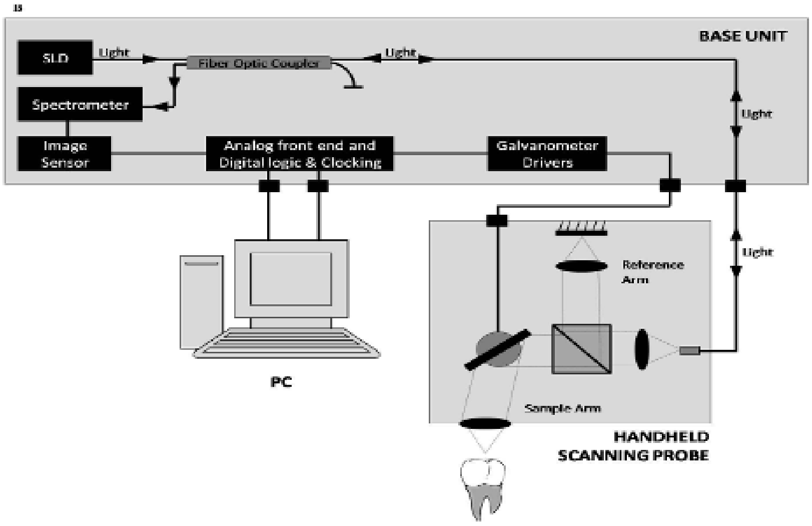

Figure 1. Schematic drawing of diagnosis system used (Adapted from Thorlabs New Jersey, USA)

For accurate quantitative measurement using OCT, it is necessary to know the refractive index of the materials being studied. Thus, the refractive index of the bonding materials was calculated. Samples of materials were obtained using a teflon mold so that the exact thickness of the material could be determined using a digital caliper (0.01 mm). After OCT image acquisition, the refractive index can then be determined using the formula: refractive index = optical distance/real distance.[20] With these data, each image was submitted to comparative analysis using ImageJ software to measure the thickness of the remnant adhesive. In addition, OCT image analysis was completed by overlapping the initial and final images using the reference metal strip as guidance.

Surface roughness

The roughness of the enamel surface was evaluated with a contact perfilometer (Mitutoyo SJ-400, Japan). Specimens were placed on the measuring table and four 1.7-mm readings were taken in the longitudinal and transverse planes over the central area of the tooth. The measuring probe moved at a constant speed (0.1 mm/s). Ra values, defined as the arithmetic mean between peaks and valleys, were evaluated for each profile. The computer then provides a representation of the profile, as well as the complete measurement protocol.

SEM

One specimen from each of the study groups was gold-sputtered and analyzed by SEM (FEI, Quanta 200 FEG, Oregon, USA) at 300× and 5000× magnification. Whenever doubts arose about the surface composition, analysis by energy dispersive spectroscopy (EDS) was also performed.

Statistical analysis

Statistical analysis was done on the roughness values using SPSS software 13.0 (Statistical Package for the Social Sciences, Chicago, IL, USA). Means and standard deviations were calculated. Normal distributions were tested by the Kolmogorov-Smirnov test. One-way ANOVA was calculated to see if there were any differences between the groups, and in the case of statistically significant differences, the Mann-Whitney test was applied. Comparisons between mean Ra values for each group at both evaluation points were done using the Wilcoxon signed-rank test. A p value less than 0.05 was considered statistically significant for all tests.

RESULTS

The results for surface roughness were submitted to one-way ANOVA, which revealed significant differences between the groups. In order to identify the differences, Mann-Whitney two-by-two comparisons were applied. Statistically significant differences were found especially in the CI direction for the G2 group: G2 × G1 (p=0.011), G2 × G3 (p=0.009) and G2 × G4 (p=0.011). For the MD direction, differences were found only between G2 and G4 (p=0.044).

The mean Ra values are summarized in Table II. The Wilcoxon signed rank test revealed statistically significant differences between moments for G2 (p=0.010) and G4 (p=0.021) both in the CI direction.

Table II. Mean roughness values (Ra) and standard deviations for each method of removal/polishing of the remnant adhesive before and after bracket debonding

Group	CI			MD		
	Before	After	*p value**	Before	After	*p value**
G1: 30-blade tungsten carbide bur, 3-µm diamond paste and felt disk	0.41 ± 0.12	0.50 ± 0.31	*1.000*	1.03 ± 0.40	1.15 ± 0.43	*0.750*
G2: fiberglass	0.46 ± 0.14	0.66 ± 0.11	*0.010*	1.45 ± 0.25	1.39 ± 0.27	*0.646*
G3: laser ER:YAG	0.38 ± 0.93	0.49 ± 0.19	*0.214*	1.00 ± 0.44	1.04 ± 0.46	*0.678*
G4: 30-blade tungsten carbide bur and aluminum oxide	0.31 ± 0.10	0.51 ± 0.12	*0.021*	1.04 ± 0.44	1.06 ± 0.44	*0.859*

*Wilcoxon signed rank test.

Cross-sectional OCT image analysis showed almost no differences between G1 and G4. However, although G2 showed slight remnants of adhesive in almost all specimens, some enamel loss was evident in G3, but not in all the specimens. Considering the refraction index of Transbond™ XT (1.58) and the adhesive (1.55), the mean values of remnant adhesive and enamel loss from each group are shown in Table III.

Table III. A mean of remnant adhesive and enamel loss from each group and the total mean of groups.

Groups	**Enamel loss (µm)**	**Remnant adhesive (µm)**
G1	20.5	14.3
G2	3.0	26.9
G3	37.9	9,7
G4	6.0	2.6

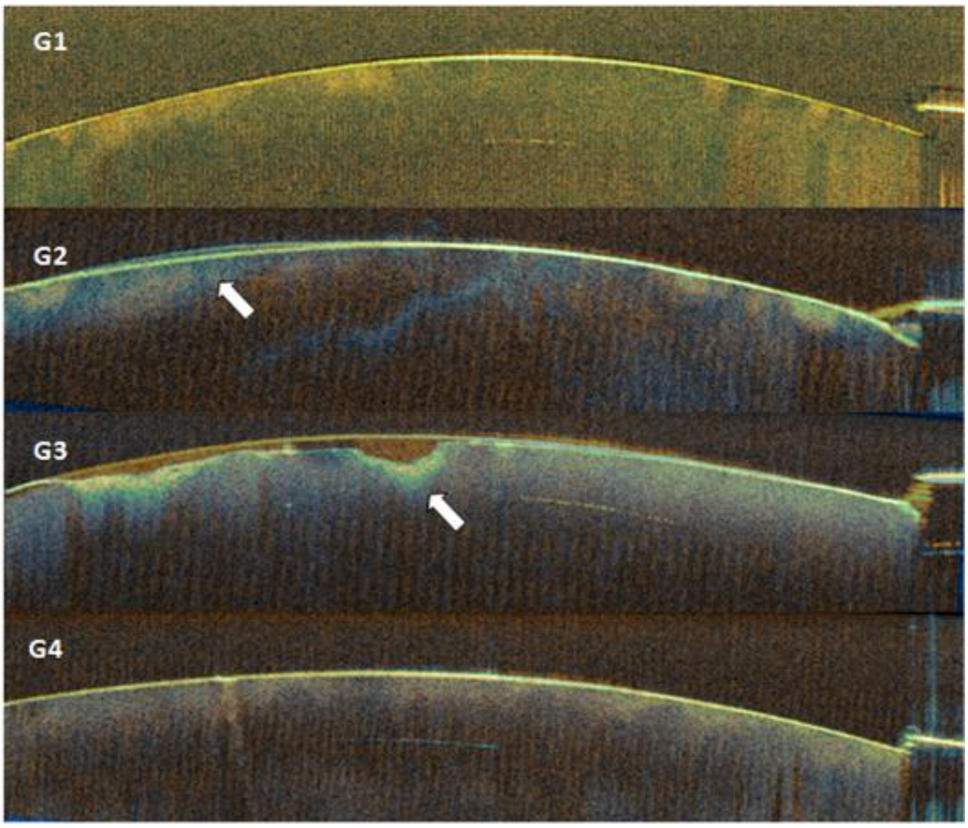

Figure 2. Axial section images: overlapped layers before and after cleaning up procedure. G1 and G4 showed almost same aspect before and after, while G2 showed a adhesive excess and G3, enamel loss.

En-face OCT image analysis demonstrated that G1 and G4 had a satisfactory surface aspect. From the images of G1, G2 and G4 it was possible to observe effects of acid etching over the enamel surface. However, G1 obtained the most satisfactory surface aspect, followed by G4 and G2. Some enamel loss could also be observed in G3 (Figs 2 and 3).

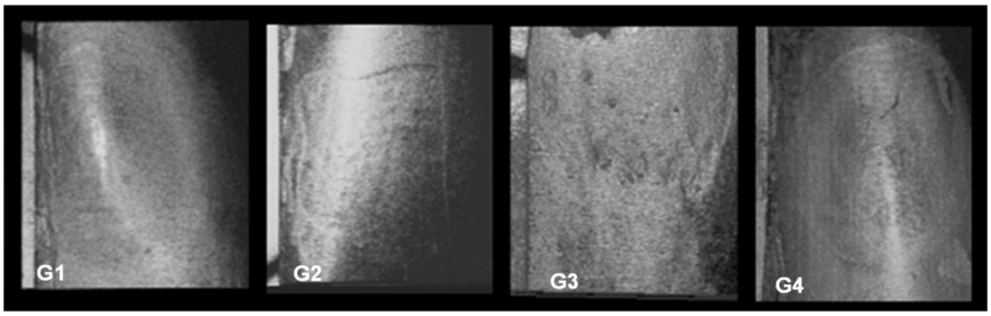

Figure 3. *En-face* OCT final images after adhesive removal and polishing procedures.

SEM analysis revealed damage to the enamel surface for all groups. G1 had the least amount of damage, with some horizontal and vertical scratches. Remnant resin was observed in G2 and some areas of enamel loss in G3. G4 presented images similar to G1 (Fig 4).

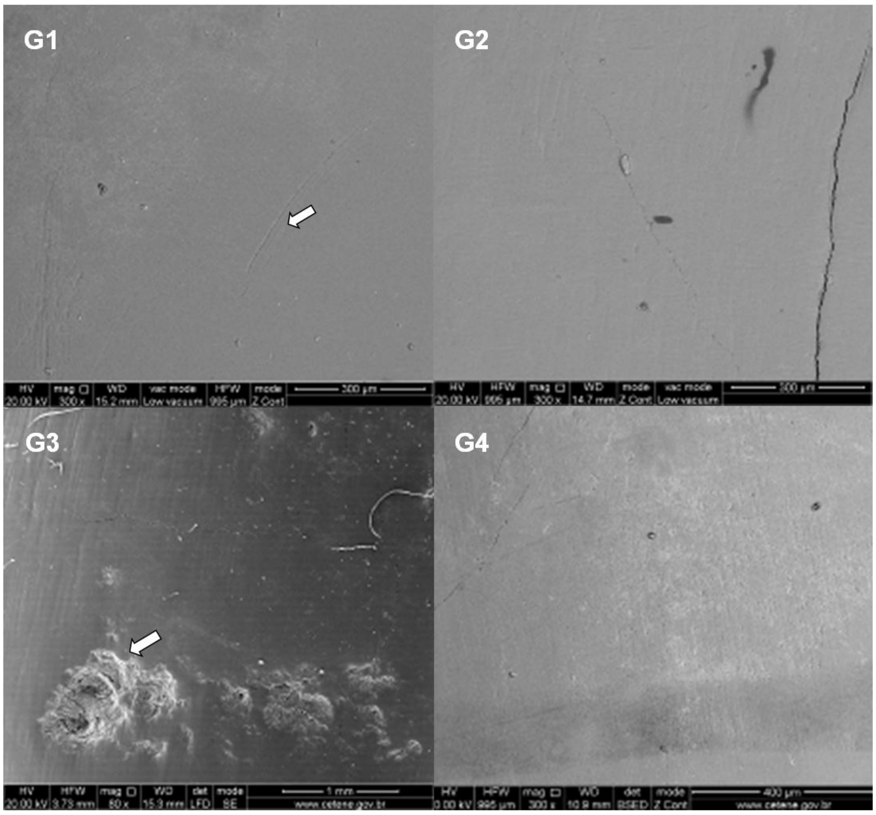

Figure 4. SEM images of the final enamel surface (300x). (G1) surface with vertical and horizontal deep scratches (arrow); (G2) presence of remnant primer/adhesive on enamel surface; (G3) carbonized area on enamel surface (arrow); (G4) surface with similar aspect as to G1.

EDS analysis was performed in order to identify different regions and alterations to the enamel surface found in G2 and G3. For the former, a significant presence of carbon and silica was found (Fig 5A). For the latter, the EDS test revealed a decrease percentage calcium and phosphor, but also an increase percentage of silica and carbon on punctual damage areas (Fig 5B).

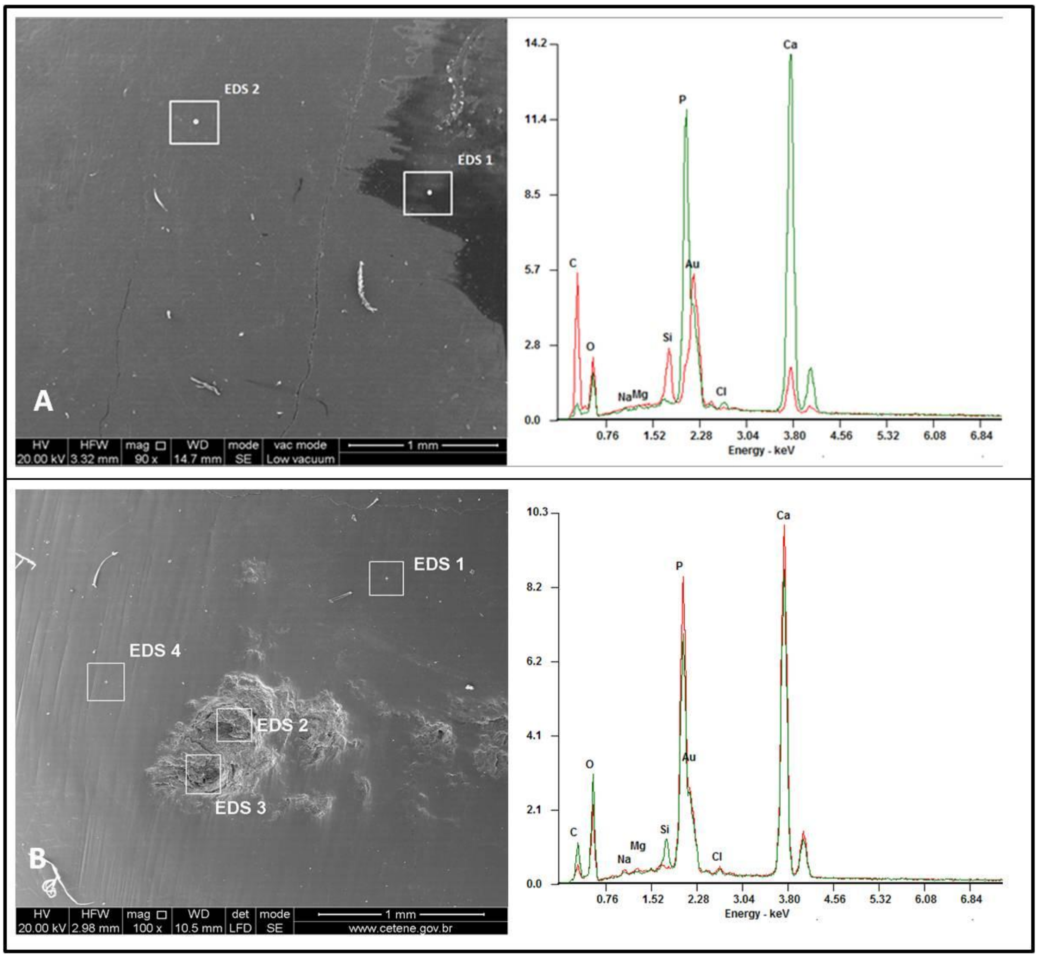

Figure 5. EDS analysis. EDS 1 and EDS 2 are represented as a red and green line, respectively. (A) G2: EDS 1 remnant adhesive area and EDS 2 enamel surface; (B) G3: EDS 1 and 4 in enamel surface area and EDS 2 and 3, carbonized area.

DISCUSSION

Smoothness is an inherent characteristic of the enamel surface and it can be measured by the degree of roughness. Most dental procedures can increase enamel roughness and thus promote some tissue damage, for example, removal of remnant adhesive after orthodontic bracket debonding.

Bovine lower incisors were used in the present study as a substitute for human premolars. As well as the similarities between both enamel substrates, bovine incisors were also chosen because of the less convex buccal area, favoring OCT image acquisition. Human upper incisors could also have been used, but the difficulties in collecting these specimens also led us to use bovine teeth.

Significant differences were found between the CI and MD directions in agreement with another study.[6] The MD direction presented higher Ra values than the CI direction, which may occur because the latter presents a much flatter surface and the MD direction is influenced by the convexity of the enamel surface. Comparison of the Ra values between both evaluation points showed that the method of removal of remnant adhesive directly influenced the roughness of the enamel, with statistically significant differences found for G2 and G4 in the CI direction, rejecting the first null hypothesis. Interestingly, surface roughness increase was not observed for G3, despite the fact that for some specimens tissue damage was also observed.

In roughness analysis, no significant differences were found between the two groups that used the carbide tungsten bur to remove the remnant adhesive, despite the polishing method used (diamond paste and felt disk or aluminum oxide). This is in agreement with the SEM observations in this study and previous published results, which considered carbide burs the fastest and more efficient method to remove remnant adhesive after bracket debonding.[1,5,11,12] The presence of horizontal and vertical scratches is considered to be a common pattern.[11,22,23] These studies highlight the importance of a complementary polishing step. Because bonding adhesives are abrasion resistant and they generally match the tooth color, complete removal of bonding adhesive is quite a difficult task. Polishing procedures are then very important as they can reduce surface roughness by 26% to 74%.[1,24,25] Omitting this step can lead to plaque accumulation, gingival inflammation, tooth demineralization and staining, marginal discoloration, and patient discomfort.[6,11–13,26,27]

In addition, comparisons between G1, G4, and G3 did not reveal any differences between them. Laser Er:YAG has been described as the method that promotes less damage to the enamel surface even compared with tungsten carbide bur.[14,15] This is not in agreement with our results, considering the fact that the laser treated group obtained the highest enamel loss. However, this group obtained satisfactory remnant resin removal an excellent clinical aspect that could be observed after treatment in the enamel area which were under remnant resin layer. SEM evaluations revealed some horizontal cracks that cannot be attributed only to removal or debonding procedures; they could be an effect of the heating due to the laser or dryness of the teeth.

The type of interaction also depends on the wavelength and power density of the laser radiation used.[29,30] . Laser Er:YAG presents high absorption by hydroxyapatite and water, in this procedure water volume was sufficient to transfer the heat from the laser to the adhesive surface. The water absorbs the radiation and through thermal or photo ablation vaporizes the monomer, breaking the bond between the adhesive/enamel interface[28] and making the remnant adhesive easy to remove without causing any damage to the enamel surface and avoiding the need for polishing.[8,14] However, some limiting factors of the present study such as the use of non-contact laser hand-piece and a moderate water flow in order to promote better surface visualization, could justify some signs of carbonization or fusion on the enamel surface.

Roughness in G2 showed significant differences between this group and all the other groups, especially in the CI direction. The new composite bur, reinforced by fiberglass, has been indicated for clean-up procedures after debonding and its manufacturer advocates that it removes the adhesive without causing damage to the enamel surface.[8] However, in this study, complete removal of remnant resin layer was not observed and enamel surface roughness increased. Substantial wear of these burs occurred in our study during the removal procedure extending the time taken to totally remove the adhesive, leading to heat generation. This led us to remove the thicker adhesive layers with a more abrasive tip, such as a carbide bur, and then use the fiberglass tips to remove the fine remnant adhesive, closer to the enamel.

Further EDS analysis for G2 and G3 confirmed the hypothesis of differences found on the enamel surface. For the fiberglass group, a higher percentage of silica and carbon was found which corresponds to the main components of the bonding agent (Transbond^{TM} XT).

For the laser group, EDS revealed a decrease of calcium and phosphor on punctual damage areas previously mentioned, although a small percentage of carbon and silica on intact surface suggest thin layer of the bonding agent (Transbond^{TM} XT). However, the laser effects observed under SEM do not correspond to the mean roughness results obtained in the present study. This is probably because the laser led to damage only around the impression of the bracket area, preserving the area under the remnant adhesive during the removal procedure. Thus, the high-power laser can be considered as an alternative; however more studies should be done using this technique before clinical application.

The OCT images made it possible to reveal the residual adhesive layer after clean-up procedures even though the enamel appeared macroscopically clean.[31] Cross-sectional OCT images permitted precise measurement of the amount of adhesive and enamel loss. However, this enamel loss generally appeared in areas where the laser was punctually activated. Better results could have been obtained if this group had undergone final polishing.[11,13,22,25] Only G1 and G3 groups presented enamel loss higher than 20 µm, which corresponds to the enamel layer with more fluoride content. Yet, it must be taken into consideration that previous steps could also favor enamel loss, such as prophylaxis, acid etching, and bracket debonding. On the other hand, *en-face*

OCT images allow more detailed analysis than clinical observation. This rejects the second null hypothesis, considering specific differences and particularities between evaluation methods.

Thus, the implementation and evaluation of new technologies for remnant adhesive removal after bracket debonding are very important to provide benefits to patients and dentists. Small details that can directly interfere in the maintenance of oral health and aesthetics can be observed using OCT images. In addition, the possibility of performing OCT analysis *in vivo* increases the benefits of this method.[17–21,32–34]

CONCLUSIONS

Enamel surface roughness is directly affected by the clean-up method used to remove residual adhesive after bracket debonding. Considering the limitations of this in vitro study, no clean-up method was considered perfect. However, the use of the tungsten carbide bur provided the fewest superficial changes regardless of the polishing method, and was found to be an important step for the recovery of part of the smoothness of the enamel surface. The use of Er:YAG laser produced the highest enamel loss. On the other hand, the use of fiberglass did not contribute to higher enamel loss, but, a lower polishing capacity favoured a higher remnant resin layer and consequently a much rougher surface was obtained after its use.

All methods of evaluation used here were important to characterize surface alterations after bracket debonding and removal of adhesive; each had its own characteristics. However, amongst the methods studied, OCT analysis allowed the determination of the exact thickness of remnant adhesive and/or enamel loss and also surface evaluation. The possibility of performing *in vivo* analysis increases the benefits of this method.

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5 Considerações Finais

CONSIDERAÇÕES FINAIS

Os resultados encontrados nos estudos acima sugerem que a avaliação do esmalte através da microscopia óptica e da tomografia de coerência óptica em 3D é considerada satisfatória para avaliar o Índice de Adesivo Remanescente. A TCO 2D mostrou-se um método preciso para mensurar a quantidade de resina remanescente sobre a superfície do esmalte, sendo um bom aliado para pesquisas futuras. Estes resultados indicam que análise visual qualitativa usando o IAR é capaz de gerar resultados similares aos avaliados por análises quantitativas da imagem.

Todas as técnicas de descolagem de *bracket* usadas para remover *bracket* metálicos foram efetivas. As vantagens e desvantagens de cada técnica foram discutidas em detalhes, e de um modo geral mostrou que a descolagem por alicate removedor de *bracket* apresentou predominantemente fratura na interface *bracket*/resina, a qual preserva mais a estrutura de esmalte que a descolagem através da pistola, a qual deixou uma pequena quantidade de resina na superfície do esmalte quando da descolagem dos *bracket*, acarretando uma fratura predominantemente na interface esmalte/ resina, que pode ser muito perigosa para este tecido.

Nenhum método de acabamento da superfície foi considerado perfeito e pode-se concluir que o método usado para o acabamento de cada dente interferiu de forma direta variação da rugosidade após o procedimento nos diferentes grupos. O grupo do laser promoveu a maior perda de esmalte dentário. Por outro lado, o grupo da fiberglass não contribuiu para a perda de esmalte e sim, através de uma capacidade reduzida de polimento, apresentou a maior camada de resina remanescente e consequentemente uma alta rugosidade foi produzida por esta broca.

Todos os métodos de avaliação foram importantes para caracterizar alterações na superfície após a descolagem do bracket e remoção da resina remanescente; cada um com suas características. Entretanto, entre os métodos estudados, a análise em TCO apresenta a possibilidade de análises in vivo, que aumenta os benefícios deste método.

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