Efficacité d'un laser Er:YAG versus taille à la fraise et des adhésifs universels monocomposants dans l'adaptation marginale des restaurations de classe V

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Intitulée :

Efficacité d'un laser Er:YAG *versus* préparation à la fraise et des adhésifs universels mono-composants dans l'adaptation marginale des restaurations de classe V.

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Résumé

Objectif : Cette étude a évalué l'effet d'un laser dentaire dans l'adaptation marginale de restaurations avec des marges de dentine et d'émail, en comparaison aux cavités percées au moyen d'une fraise dentaire, suite à l'utilisation de la dernière génération de systèmes adhésifs mono-composant.
Matériels et méthodes : Quatre-vingt-seize cavités de classe V ont été testées (douze groupes, n=8)
Résultats : Après fatigue, les pourcentages les plus bas d'adaptation marginale ont été observés pour les groupes 1 et 4 et le pourcentage le plus important de marge de fermeture atteint pour les groupes 3 et 6.
Conclusions : la qualité de l'adaptation marginale obtenue par les restaurations dont les cavités ont été traitées à base de laser a été moindre que celle obtenue par les restaurations dont les cavités ont été traitées par perçage. L'utilisation de différents paramètres, notamment la durée relativement longue de la pulsation de laser, pourrait expliquer ces résultats

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Thèse préparée sous la direction de PD Tissiana BORTOLOTTO et Professeur Ivo KREJCI

Efficacité d'un laser Er:YAG *versus* préparation à la fraise et des adhésifs universels mono-composants dans l'adaptation marginale des restaurations de classe V.

Thèse

présentée à la Faculté de Médecine

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Putri Noerpuspita

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RESUME

Objectif : Cette étude a évalué l'effet d'un laser dentaire Erbium dans l'adaptation marginale de restaurations avec des marges de dentine et d'émail, en comparaison de cavités percées au moyen d'une fraise dentaire, au travers de l'utilisation de la dernière génération de systèmes adhésifs mono-composant.

Matériels et méthodes : Quatre-vingt-seize cavités de classe V ont été réalisées (douze groupes, n=8). Six groupes ont été traités par une perceuse dentaire conventionnelle et les six autres avec un laser (Pluser, LAMBDA SpA, Brendola, Italie). Quatre adhésifs auto-mordançant mono-composant (Gr. 1 et 4: ELS Unibond, Gr. 2: All Bond Universal, Gr. 5: SKB-100 et Gr. 6: Prime & Bond Active) ont été évalués ainsi que l'adhésif auto-mordançant à 2-composants, Clearfil SE Bond (Gr. 3), lequel a été utilisé comme contrôle positif. Le composite Clearfil Majesty a été utilisé comme un matériau de restauration. En addition à ce dernier, un groupe (Gr. 1) a été restauré avec un composite à faible rétrécissement (ELS composite) et utilisé conjointement avec son adhésif respectif (ELS Unibond). Les pourcentages d'adaptation marginale ont été évalués et comparés quantitativement avec un microscopie électronique à balayage avant et après un test de fatigue (charge thermomécanique).

Résultats: Avant et après le test de fatigue, une analyse statistique opérée sur les données collectées a démontré une performance significativement meilleure dans les marges dentaires de cavités ont été preparées à la fraise en comparaison de celles traitées par laser. Quant aux groupes, les scores les plus bas d'adaptation marginale avant fatigue ont été obtenus pour le groupe 4, et le plus haut pourcentage de marges continues constaté pour les groupes 3 et 6. Après fatigue, les scores les plus bas d'adaptation marginale ont été observés pour les groupes 1 et 4 et le plus haut pourcentage de marges continues atteint pour les groupes 3 et 6.

Conclusions: La qualité de l'adaptation marginale obtenue par les restaurations dont les cavités ont été traitées à base de laser a été moindre que celle obtenue par les restaurations dont les cavités ont été préparées à la fraise. Différents paramètres, notamment la

durée relativement longue de pulsation de laser, ont pu amoindrir la qualité de l'interface adhésive et par conséquent l'adaptation marginale de l'émail et de la dentine. La performance de deux adhésifs universels a été aussi bonne que celle du contrôle positif.

INTRODUCTION

La dentisterie restauratrice moderne tend de plus en plus vers la durabilité, la conservation et le confort de restauration. Ces qualités s'inscrivent bien dans le concept de la Dentisterie Minimale Invasive (DIM), présenté comme l'aspect le plus important de la dentisterie restauratrice moderne (Erickson et al. 2003). Ce concept a rejeté une théorie de l'extension de la prévention initiée par GV. Black en 1917 (Black 1908). Les objectifs de la DIM se concentrent sur la préservation, la réduction de l'invasion bactérienne, la reminéralisation, des interventions chirurgicales minimales et la réparation au lieu du remplacement. Ce concept permet également le traitement adéquat des tissus carieux sans retrait excessif de tissus dentaires sains (Jingarwar et al. 2014).

Les systèmes adhésifs ont été introduits il y a plus de soixante ans et ont évolué au cours des décennies suivantes, passant du simple collage de l'émail aux systèmes adhésifs universels à un composant (Van Meerbeek et al. 2003, Giannini et al. 2015). Depuis lors, grâce à des études approfondies dans le domaine, les systèmes adhésifs ont été considérablement améliorés. Dans les années 1990, la révolution des systèmes adhésifs a commencé avec l'introduction de systèmes de mordançage total en trois étapes. Avec ces systèmes, après rinçage de la dentine mordancée, un primer hydrophile est utilisé avant l'application d'une couche uniforme de bond (Sofan et al. 2017). Depuis lors, les systèmes adhésifs se sont améliorés et de nombreuses études ont été entreprises pour modifier leurs compositions ainsi que les procédures de production.

Une autre étape dans le développement de systèmes adhésifs a été l'introduction d'adhésifs auto mordançants. Ces systèmes ont été développés pour résoudre un problème lié à la déminéralisation de la dentine par gravure à l'acide phosphorique. Généralement, ils sont différents de la gravure et du rinçage non seulement dans les procédures, mais également dans le type de monomère acide mis en oeuvre, le nombre de bouteilles, la proportion entre le solvant et l'eau, le pH initial et le caractère de la couche adhésive (Sundfeld et al. 2005). L'utilisation du primer auto mordançant, qui est la première étape dans l'application d'adhésifs auto mordançants, ne nécessite pas de rinçage avant d'appliquer le collage. Il mordance et infiltre les substrats dentaires simultanément (Peumans et al. 2010). Ainsi, il permet une technique clinique moins sujette à la sensibilité dentaire et plus abordable pour son utilisateur. De plus, la mise en oeuvre des adhésifs auto mordançants présente des variations telles que l'application en deux étapes d'un primer et d'une résine adhésive séparément dans deux récipients, ou, pour des raisons de simplification, celle d'un adhésif auto mordançant en une étape. Ce dernier, présenté dans un unique récipient, contient de l'eau, des additifs, un solvant et des monomères (Reis et al. 2007). Le principal avantage est son efficacité car il permet de raccourcir la durée d'assise des patients.

Le méthacryloyloxydécyl dihydrogénophosphate-10 (10-MDP), considéré comme le monomère fonctionnel le plus courant, contient un groupe de méthacrylates qui réagit avec d'autres monomères par réticulation et un groupe phosphate permettant le mordançage des tissus durs (Van Landuyt et al. 2008). Il a le potentiel de se lier ioniquement avec le calcium dans l'hydroxyapatite (Yoshioka et al. 2002, Yoshida et al. 2000). En conséquence, ce système adhésif permet d'améliorer la résistance à la dégradation au niveau de l'interface entre l'adhésif et le tissu dentaire (Yoshida et al. 2000).

La dentine, avec sa structure et sa morphologie complexes, constitue un substrat difficile à coller, contraignant la profession dentaire à rechercher constamment des systèmes adhésifs plus efficaces, moins sensibles à la technique et simples d'utilisation (Van Meerbeek et al.2006). Il est reconnu que certains systèmes adhésifs auto mordançants n'ont pas obtenu les résultats escomptés en raison de l'encapsulation incomplète du smear layer (Camps et Pashley 2000). Comme les adhésifs auto mordançants incorporent la smear layer dans la couche hybride, la technique de préparation des cavités a également un rôle important sur la structure et l'épaisseur de la smear layer (Carvalho et al. 2005). Son intérêt se manifeste particulièrement lors de l'utilisation d'adhésifs auto mordançants qui, contrairement aux adhésifs de mordançage et rinçage, préservent la smear layer.

Le laser Erbium YAG (Er:YAG), laser dentaire avec une longueur d'onde d'émission de 2940 nm, constituant la longueur d'onde optimale à absorber par l'eau et l'hydroxyapatite, a désormais acquis une popularité certaine (Bader et Krejci 2006). Reposant sur un concept thermomécanique, il permet l'ablation simultanée de la dentine et de l'émail par vaporisation d'eau, ce qui crée des micro-explosions humides, conduisant à l'élimination mécanique de la dentine et de l'émail (Hilbst et al. 2002). Néanmoins, une combinaison spécifique de différents paramètres est nécessaire pour empêcher la destruction de tissus lors de l'ablation (Abdulsamee 2017).

Des recherches antérieures ont montré que les lasers Er:YAG éliminent la dentine en laissant un motif irrégulier, i.e. micro-rétentif avec des tubules dentinaires ouverts et sans smear layer, à la surface de la dentine (Harashima et al. 2005, Carvalho et al. 2011). Cependant, l'effet des lasers Er:YAG sur l'adhésion dentaire est toujours remis en question (Ramos et al. 2010). Néanmoins, une telle surface de dentine avec des tubules dentinaires ouverts et sans smear layer résultant de l'ablation au laser, conviendrait parfaitement au collage (Carvalho et al.2011). Le défi est de trouver la combinaison idéale des paramètres du laser pour permettre l'ablation de l'émail et de la dentine sans endommager la structure dentaire.

Pour déterminer le potentiel du laser par rapport au preparation conventionnel, dans le contexte de la préparation de cavités selon la philosophie suivie par la Dentisterie Minimale Invasive (MID), le but de cette étude était d'étudier l'effet du laser dentaire combiné avec la dernière génération d'adhésifs à un composant sur la qualité des restaurations adhésives. L'adaptation marginale des restaurations adhésives opérées sur l'émail et la dentine a été évaluée avant et après simulation d'opérations telles que des stimulations mécaniques et thermiques, sous l'influence de liquide dentinaire simulé. Les hypothèses nulles reposaient sur le fait que : 1. il n'y aurait pas de différence statistique significative entre les groupes traités au laser et ceux traités à la fraise dentaire et 2. il n'y aurait pas de différence statistique significative entre les adhésifs mono composants et le contrôle positif.

ABSTRACT

Purpose: This study compared the effect of dental laser and bur-drilled generated cavities on the marginal adaptation in restorations with enamel and denting margins when using the latest generation of one component adhesive systems.

Materials and methods: Ninety-six class V cavities were performed (12 groups, n=8), six of them treated by conventional dental drill and six of them treated with an erbium laser (Pluser, LAMBDA SpA, Brendola, Italy). Four one-component self-etching adhesives (Gr. 1 and 4: Unibond ELS adhesive, Gr. 2: All Bond Universal, Gr. 5: SKB-100 and Gr. 6: Prime & Bond Active) were evaluated and the two-component self-etch adhesive, Clearfil SE Bond (Gr. 3), served as the positive control. Clearfil Majesty composite was used as restorative material. In addition to this material, one group (Gr. 1) was restored with a low-shrinking composite (ELS composite) and used together with its respective adhesive (Unibond). The percentages of marginal adaptation were evaluated and quantitatively compared with SEM before/after thermo-mechanical loading (TML).

Results: Before and after TML, statistical analysis performed in pooled data showed a significantly better performance in margins of bur-prepared cavities in comparison to laser-prepared ones. In respect to the groups, the lowest scores of marginal adaptation before loading were observed in group 4 with the highest %CM in groups 3 and 6. After loading, the lowest scores of marginal adaptation were observed in group 4 and group 1 and the highest %CM in groups 3 and 6.

Conclusions: The quality of marginal adaptation delivered by restorations whose cavities were laser-prepared was not as effective as the one delivered by bur-prepared restorations. The different parameters, especially a relatively long pulse duration, might have affected the quality of the adhesive interface and therefore marginal adaptation on enamel and dentin. Two universal adhesives performed equally well as the positive control.

INTRODUCTION

Contemporary restorative dentistry is more and more heading towards durability, conservation and restoration comfort. These qualities suit well into the concept of Minimal Invasive Dentistry (MID) widely introduced as the most important aspect of modern restorative dentistry (Erickson et al. 2003). This concept dismissed a theory of extension for prevention initiated by GV. Black in 1917 (Black 1917). The goal of MID actually concentrates on preservation, reduction of bacterial invasion, remineralization, minimum surgical interventions and repair instead of replacement. This concept also allows the adequate treatment of carious tissue without excessive removal of sound dental tissues (Jingarwar et al. 2014).

Direct-resin composites are well-known dental materials that support this concept due to their physical properties (Cardoso et al. 2011). In addition, no destructive retentive cavity preparation is needed for resin composite to gain mechanical retention, as their retention relies on the efficiency of an adhesive system (Cardoso et al. 2011). Although resin composites have been extensively improved, failure of marginal adaptation still represents a challenge: secondary caries, sensitivity, postoperative discomfort and marginal discoloration may be some major consequences of inadequate marginal adaptation (Rodrigues et al. 2010). In this regard, dental adhesives used to bond to cavity walls, as well as the manner in which the cavities are prepared before adhesive procedures are important factors affecting restorations' marginal seal and therefore, clinical performance.

Adhesive systems: the evolution from multi- to one-component

Adhesive systems have been introduced over 60 years ago and evolved during the following decades from simple enamel bonding to universal one-component adhesive systems (Van Meerbeek et al. 2003, Giannini et al. 2015). Since then, due to extensive studies in the field, adhesive systems have been considerably improved.

The idea of adhesive systems was initiated by Dr. Hagger, a Swiss chemist in 1949. At that time, he found a way of combining a ''cavity seal'' material with ''Sevriton'', a chemical curing poly (methyl methacrylate) (PMMA) resin (Söderholm et al. 2007). Glycerol

Phosphoric acid dimethacrylate (GPDM) was a major component in his product, this acidic monomer was able to etch and interact with tooth surface creating a chemical/physical bonding between restoration and tooth (Söderholm et al. 2007). In 1952, Mclean and Kramer showed that ''Sevriton cavity seal'' was effective on dentin as a bonding agent (Mclean et al. 1952).

In 1955, Buonocore (1955) found that adhesion not only could work on dentin but also on enamel by using acid etching. At that time, he tried to observe how acid etching interacted with enamel in order to provide retention for acrylic restorations (Buonocore 1955). In 1960s, Buonocore postulated that enamel could also act as a substrate for bonding (Buonocore 1968).

In 1980, the so-called total-etch concept was proposed by Fusayama (1988), where the smear layer was removed from the prepared cavity surface by phosphoric acid. He postulated that etching could work on both substrates, enamel and dentin (Söderholm 2007). However, this concept has been challenged for a long period of time by the controversy on its biocompatibility since dentin is in direct connection to the pulp via odontoblasts, thus etching of dentin with phosphoric acid may have a negative impact on the pulpal tissue (Sofan et al. 2017).

In 1982, Nakabayashi initiated the concept of ''hybrid layer formation''. He demonstrated by SEM investigations that bonding resin had the ability to infiltrate into acid-etched dentin to create an intermediate layer consisting of collagen fibrils and resin and he postulated that this layer was the predominant mechanism of bonding to dentin (Dalkilic et al. 2012).

In 1990s the revolution of adhesive systems started by the introduction of three-step total-etch systems. With these systems, after rinsing off the etched dentin, a hydrophilic primer is used before the application of a uniform layer of an amphiphilic resin (Sofan et al. 2017). Since then, adhesive systems gained improvements and many studies have been undertaken to modify their compositions, procedures and effectiveness to produce better adhesive systems.

A further step in the development of adhesive systems was the introduction of self-etch adhesives. These systems have been evolved to solve a problem related to demineralization of dentin by phosphoric acid etch. Generally, they are different from etch and rinse not only in procedures, but also different in monomer acidic type, number of bottles, ratio between solvent and water, initial pH, and the character of the adhesive layer (Sundfeld et al. 2005). The so called self-etching primer which is the first step in the application of self-etching adhesives, does not require a rinsing off before applying the bonding, it etches and primes the dental substrates simultaneously (Peumans et al. 2010). Thus, it provides clinical less sensitivity technique and is more user-friendly. In addition, self-etch adhesives have variations including two steps application consisting of primer and adhesive resin separately in two bottles, or one-step-self-etch-adhesive, created to simplify the application, that contains water, additives, solvent, and monomers in one bottle and single application (Reis et al. 2007). The main advantage is its efficiency since it is able to shorten the patients' chair-time. This kind of adhesive system is classified as seventh generation of bonding system, being introduced in late 1999 and early 2005 (Sofan et al. 2017).

Monomers of self-etch adhesive systems consist of acidic adhesive monomers, cross-linking monomers and additional monofunctional co-monomers (Moszner et al. 2005). Acidic adhesive monomers of self-etching systems can be divided into phosphorus containing monomer and polymerizable carboxylic acid. Phosphorus containing monomers (i.e. phosphonic acid or phosphates acid), whose pH is higher compared to conventional phosphoric acid etch, simultaneously etch to enamel and dentin leading to diffusion of these monomers into underlying dentin (Sensi et al. 2007).

Methacryloyloxydecyl dihydrogen phosphate-10 (10-MDP) is well-known as the most popular functional monomer that contain group of methacrylates which react with other monomers through cross-linking and a phosphate group to etch dental hard tissue (Van Landuyt et al. 2008). It has the potential to ionically bind with calcium in hydroxyapatite, creating a self-encountered nano-layered structure by forming stable 10-MDP through hydrolytic reaction (Yoshioka et al. 2002, Yoshida et al. 2000). As a result, this adhesive system helps to enhance the resistance to degradation on interface between adhesive and dental tissue (Yoshida et al. 2000). Meanwhile, while other functional monomers have been introduced as well i.e. phenyl-P and 4-META, studies could show that these monomers have lower bond strengths and solubility stability than 10-MDP (Peumans et al. 2005, Tay and Pashley 2001, Van Landuyt et al. 2008). In addition, the role of water in self-etch adhesve system is important as well, as it works as a medium for acidic monomers and ionization (Van Meerbeek et al. 2011).

Self-etch adhesive systems are also classified based on their acidity (Tay and Pashley 2001) as mild (pH ≥ 2), intermediate (pH = ~1.5), and strong (pH ≤ 1). The mild self-etch adhesive usually forms a layer no deeper than 1 µm and resin tags are barely observed (De Munck et al. 2005). Due to its low acidity it does not remove smear layer or demineralizes the dentin completely, hence the smear layer merges together into adhesive layer and some hydroxyapatite crystal around the collagen fibrils still remain (De Munck et al. 2005, Sensi et al. 2007). This remnant is believed to serve as an additional substrate for chemical adhesion, which is advantageous to provide better strength and durability of the adhesive (Yoshida et al. 2004). On the other hand, the ''strong self-etch adhesive system'' produces deeper demineralized layer both of dentin and enamel (Van Meerbeek et al. 2011) and it has a morphological characteristic which is similar to rinse-etch adhesive system. It is capable of removing almost all the smear layer but does not remove calcium phosphates (De Munck et al. 2005). These calcium phosphates seem to have a negative impact due to their low hydrolytic stability while interacting with an exposed collagen, thus they can weaken the integrity of the adhesive interface on the long-term (Van Landuyt et al. 2005). Intermediate self-etch adhesive systems have characteristics between mild and strong, thereby they have a demineralized part in bottom and upper side of the hybrid layer (Van Landuyt et al. 2005).

Dentin, with its complex structure and morphology, constitutes a challenging substrate to bond to, constraining the dental profession to constantly seek for more efficient, less technique sensitive and user-friendly adhesive systems (Van Meerbeek et al. 2006). It has been stated that some early self-etch adhesive systems failed due to incomplete encapsulation of the smear layer (Camps and Pashley 2000). As self-etching adhesives incorporate the smear layer into the hybrid layer, cavity preparation technique has also an important role on the structure and thickness of the smear layer (Carvalho et al. 2005). Especially when dealing with self-etching adhesives that, contrary to etch & rinse ones, preserve the smear layer.

Lasers for cavity preparation

Modern dental treatments ask for new technologies and techniques to improve the minimally invasive-dentistry concept and to provide more comfortable treatments for patients. The introduction of dental lasers is a promising technology in dentistry which in certain instances may replace conventional drills (Hibst 2002). Lasers have been introduced into the dental field in the 1960s (Van As 2004). Studies have been conducted to produce more comfortable and acceptable dental lasers for efficient patients' time-seat and to provide with less sensitivity during cavity preparation compared to conventional drills (Krejci et al. 1992).

Erbium dental lasers are used for many purposes in dentistry such as removal of dental caries, tooth etching and soft-tissue surgery. There are several variations of this type of laser with different wavelengths; Er:YAG (λ = 2.94 μm), Er,Cr:YSGG (λ = 2.78 μm), Er:YLF (λ = 2.81 μm) and CTE:YAG (λ = 2.69 μm) (Aranha et al. 2007). Studies involving erbium lasers have been conducted during years to select which are the best parameters and wavelengths that are suitable for caries removal and cavity preparation without creating any damages in the dental pulpal (Bader & Krejci 2006). Erbium:yttrium aluminum-garnet (Er:YAG) and Erbium,Chromium:Yttrium-Scandium-Gallium-Garnet (Er,Cr:YSGG) are the most popular in dentistry nowadays for the removal of hard tissue (Gökçe et al. 2017). These two lasers have the highest absorption of water hence they work well on dental hard tissue compared to others such as CO_2 (Carbon dioxide laser) and Holmium:YAG lasers. However, Er:YAG and Er:YSGG lasers operate on different coefficient of absorption on water, Er:YAG lasers have three times higher absorption than Er,Cr:YSGG lasers thus less energy and time is needed for ablating the dental hard tissue due to a depthless penetration (Diaci & Gaspirc 2012). In addition, during ablation, Er: YAG will produce temperatures of up to 300°C and Er:YSGG will reach temperatures up to 800°C (Abdulsamee 2017).

Erbium YAG (Er:YAG) laser is well-known as a dental laser with the emission wavelength of 2940 nm, being the optimal wavelength to be absorbed by water and hydroxyapatite as well (Bader & Krejci 2006). Working with a thermo-mechanical concept, it can ablate dentin and enamel simultaneously by vaporizing of water which creates damp micro explosions, leading to mechanical removal of dentin and enamel (Hilbst et al. 2002). Nevertheless, a specific combination of different parameters is needed to prevent tissue destruction during ablation in dentin and enamel (Abdulsamee 2017). Some studies concluded that the quality of outcome by using erbium dental lasers depend on several parameters such as power, pulse energy, pulse frequency, beam diameter, pulse duration, air pressure and water flow rate (Diaci & Gaspirc 2012). The supply of water is also a very important factor because the water spray will help to release thermal stresses in surrounding tissues, preventing overheating (Van As 2004). The importance of water in lasers is that water is a primary chromophore absorbing the energy of laser during ablation of hard tissue (Diaci et al. 2008).

Previous research showed that Er:YAG lasers remove dentin by leaving an irregular pattern of dentin surface, leaving a micro-retentive pattern with open dentinal tubules and without any smear layer (Harashima et al. 2005, Carvalho et al. 2011). However, the effect of Er:YAG lasers on dental adhesion is still questioned (Ramos et al. 2010). Some studies reported that lased dentin provides lower bond strength compared to conventional drill (Sasaki et al. 2008). Some investigators reported no significant difference between both (Korkmaz et al. 2013) and some studies reported that dental lasers show more damaging fractures in dentin and enamel (De Munck et al. 2002). In addition, lased cavities with poor results of marginal adaptation or microleakage have been reported in studies that used high pulse energies (over 300mJ), hence polishing after cavity preparation is almost mandatory when using lasers with high energy (Bader & Krejci 2006). Notwithstanding, such dentin surface with open dentinal tubules and without smear layer, resulting from laser ablation, would be highly suitable for bonding (Carvalho et al. 2011). The challenge is to find the ideal combination of laser parameters to enable enamel and dentin ablation without damaging the tooth structure.

Marginal adaptation and detection of early adhesive failures

Marginal adaptation is a clinically relevant and one major factor to indicate the quality of restoration in terms of clinical durability and stability (Neppelenbroek 2015), indeed to create an appropriate marginal sealing still remains as a challenge related to composite shrinkage post-polymerization and stress produced on restoration (Rodrigues et al. 2010). Class V cavities are preferred to test the adhesive system performances related to their factor C (Dalkilic et al. 2012, Heintze et al. 2007). Generally, restoration shrinkage due to polymerization creates a gap on the interface area leading to stress shrinkage (Nagem et al. 2007, Lutz et al. 1991). A contraction gap will be created when the stress exceeds the bond strength between the bonding and dental substrate, affecting the restoration's durability (Rodrigues et al. 2010, Papadogiannis et al. 2009). In addition, temperature changes in the oral environment influences the marginal seal as well, this thermal stimulus resulting in thermal expansion on the restoration which is placed on the tooth that may lead to stress on the interface and result microleakage on the margin (Yan et al. 2007).

Regarding marginal seal evaluation, it has been evaluated by several *in* vitro techniques such as bacterial infiltration, compressed air, scanning electron microscope (SEM), transmission electron microscope (TEM), micro computed tomography (micro-CT), optical coherence tomography (OCT), technique of replica and dye-penetration method (Monteiro et al. 2011). Dye-penetration is a standard technique which has been used for a long time, however SEM results are more reliable related to its higher resolution, larger field, and better magnification to measure marginal adaptation (Khoroushi et al. 2018, Punithia et al. 2011). Based on the results of Rengo et al (2015) when comparing SEM and micro-CT, it was concluded that micro-CT should be equivalent to 20x SEM magnification at determining marginal leakage of Class V composite resin restorations, the main shortcoming of micro-CT being adjusting magnification to provide better view (Rengo et al. 2015).

The selection of restorative materials with optimal physical and mechanical properties, i.e. the lowest thermal expansion and modulus elasticity as closer as dentin, contributes to the preservation of the adhesive interface, leading to a more satisfying longevity (Lopes et al. 2012, Benetti et al. 2014, Xu et al. 1998). Coefficient of thermal expansion has been used to indicate how the temperature changes will change the size of material, to predict the potentials of microleakage by thermal expansion between tooth and restorative materials (Sidhu et al. 2004). Other factor that may contribute is the modulus of elasticity of composite restoration that shows a rigidity of material (Rodrigues et al. 2007). Based on Benetti et al (2014) the highest elastic moduli of composite restoration will result the lowest number of gap formation on the enamel margin.

Fatigue tests simulating intra-oral conditions

Conducting experimental research *in vivo* is always challenging due to ethical clearance, resources, and time. Thus, studies using *in vitro* methodologies intending to simulate chewing and temperature changes in the oral cavity are of common use in biomaterials' research (Frankenberger et al. 2005). Thermocycling (TC) and mechanical cycling (MC) have been widely used for the simulation of intra buccal conditions in order to render results that will be as close as possible to *in vivo* ones (Nikaido et al. 2002, Bedran-de-Castro et al. 2004, Frakenberger et al. 2005). In this context, some studies concluded that combining TC and MC (thermo-mechanical loading) simultaneously may bear a result that is more reliable (Koyuturk et al. 2008) even though the result of each study is highly varied due to the difference of cycle number, time, force magnitude and temperature (Koyuturk et al. 2008).

To determine the potential of laser in respect to conventional drill, for the preparation of cavities in the context of minimally invasive dentistry, the purpose of this study was to investigate the effect of dental laser combined with the latest generation of one-component adhesives on the quality of adhesive restorations. The marginal adaptation of adhesive restorations located on enamel and dentin was evaluated before and after simulation of oral conditions such as mechanical and thermal stresses, under the influence of simulated dentinal fluid. The null hypotheses were that 1. there would not be a significant difference between laser and bur prepared groups and 2. There would not be any significant difference between the one-bottle adhesives and the positive control.

MATERIALS AND METHODS

Materials selection for the study: The following materials were tested (Table 1): four one-component universal adhesive systems (Unibond extra low shrinking (ELS), Allbond Universal, experimental adhesive SKB-100 and Prime & Bond active) and a two component self-etch adhesive (Clearfil SE Bond) that served as the positive control. A methacrylate-based hybrid composite (Clearfil Majesty) was used to restore all cavities of the 5 groups and a low-shrinking composite (ELS composite) that was also tested when used together with its corresponding low-shrinking adhesive, Unibond ELS. Unibond ELS and ELS composite are bioholistic biomaterials manufactured by Saremco and commercialized as part of the Green Line range of products free of TEGDMA and HEMA. The rationale behind this choice was to determine if the low shrinking adhesive (Unibond ELS) could be used in combination with a conventional composite or if the use of a low shrinking composite was necessary in order to render visible the effect of using a low shrinkage adhesive on marginal adaptation.

Sample preparation: Ninety-six intact, carious-free, non-restored human third molars were randomly selected after extraction and divided into 12 groups (n=8). After cleaning with pumice and water by using rotating brush, they were sealed with an adhesive system (Optibond FL) and fixed on custom-made holders. Then the teeth were prepared for the simulation of dentinal fluid. A perforation was drilled into pulpal chamber approximately 1mm over the cemento-enamel junction (CEJ), where a metal tube was fitted into and luted with an adhesive system (Optibond FL). This tube was connected by a silicone hose with the appliance simulating the dentinal fluid (PAA Laboratories, Linz, Austria) by diluted horse serum (Lutz et al. 1991, Bortolotto et al. 2016). The dentinal fluid simulation was maintained during restoration and during the loading of the specimens in the chewing machine.

Laser-prepared cavities: Several pre-tests were conducted to avoid any damage to the tooth structure by selecting the proper laser parameters (pulse energy from 50 mJ up to 300 mJ). In six groups, class V cavities with margins located on enamel and dentin were prepared by the use of an erbium YAG laser (Pluser, doctor smile, LAMBDA SpA, Brendola, Italy) (Figure 1) with the following parameters (Table 2): wavelength= 2940 nm, pulse length= 150 µs, pulse energy = 250 mJ, power = 5W, frequency = 20 Hz, water = 80%. The handpiece boost type with non-touch tip (LOMAN 018.6) was selected and used at 1mm distance and perpendicular to the surface of the tooth. Cavity finishing was performed by using the same tip and lowering the energy with slow movement as follows: pulse energy = 150 mJ, power= 3W, frequency = 20 Hz and water = 60%. Before the application of adhesive system, the lased tooth was cleaned by strong water spray and air.

Bur-prepared cavities: In the other six groups the cavities were prepared by conventional drill. A class V cavity was performed by the same operator with consistent proportions (3.5 mm mesio- distal, 3.0 mm occluso-cervical and 1.5 mm deep) and controlled by a digital caliper and periodontal probe. The cavity was located in the cervical area of buccal side of every tooth at the transition between enamel and dentin (Bortolotto et al. 2016). A torpedo-shaped diamond bur (Intensiv SA, Montagnola, Switzerland) was used for preparation under water cooling. To avoid unsupported enamel prisms, a 1 mm bevel was made on enamel margins (Intensiv SA, Montagnola, Switzerland). The finishing was perfomed by 15-micron diamond throughout the margin to smoothen the tooth surface. Every step was checked under a stereomicroscope (Leica A60, Germany).

Restorative procedures: In regard to adhesive system application, one-bottle self-etch adhesive systems were applied in their self-etching mode (no phosphoric acid was used) following manufacturer’s instructions. Composite was inserted into the cavities with single layer technique and light-cured for 20 s with a LED curing device (DEMI Plus, Kerr, CA, USA). Restoration polishing was performed by using flexible aluminum oxide disks (SofLex Pop-On, 3M ESPE, Seefeld, Germany). The polishing result was checked under 12x magnification by using a stereomicroscope (Leica A60, Germany) and corrected if necessary.

Thermo mechanical load and replica technique: Replicas of the polished restorations were taken with a low viscosity polyvinylsiloxane impression material (President light body, ColtèneWhaledent, Altstätten, Switzerland). The teeth were stored in a bottle filled with tap water until the fatigue test. Thermal and mechanical loading (TML) was performed subsequently. It was accomplished with 240,000 occlusal mechanical loading cycles and simultaneous 600 thermal cycles between 5 and 50ºC. Lingual cusp of a human molar was used as the antagonist for the mechanical loading. The mechanical stress was carried out at 1.7 Hz and a maximal load of 49 N. Another set of replicas was taken after loading with a low viscosity polyvinylsiloxane (President, ColteneWhaladent) impression material. The impressions before and after loading were poured with epoxy resin (Epofix Resin, Struers, USA) and the epoxy replicas were gold-coated in a gold sputtering device (BT150, HHV Ltd, UK) and subsequently placed into a field emission Scanning Electron Microscope (Fe-SEM, Sigma 300 VP, Carl Zeiss Microscopy, GmbH, Jena, Germany) for marginal analysis.

Quantitative margin analysis: Analysis of the marginal adaptation in the SEM was done by one trained and experienced operator on group-blinded replicas. The criteria that were applied were the percentages of continuous margin (%CM) at the whole restoration margin length (Total Margin Length, TML), that is, the average of enamel and dentin margins.

Statistical analysis of non-parametric data was performed with IBM SPSS Statistics V 24 for Mac. The effect of thermo mechanical loading on the results before / after loading was carried out with Related-Samples Wilcoxon Signed Rank Test. Differences between pooled data of bur-prepared cavities in respect to laser-prepared ones was assessed by Mann-Whitney U Test. The differences between the 6 groups was assessed with Kruskal-Wallis and Duncan post-hoc test. The level of confidence was set to 95%.

RESULTS

A general view of the results at the TML before and after loading, for each group, according to the preparation method (bur or laser) is shown in Figures 2 and 3, respectively.

Effect of fatigue test (before vs after thermo mechanical load)

Thermo mechanical loading had a significant effect on marginal adaptation (p=0.000, Related-Samples Wilcoxon Signed Rank Test) as results of pooled data before loading at the TML were significantly higher (82±14) than results after loading (66±24).

Effect of cavity preparation method (bur vs laser)

Before loading, statistical analysis performed in pooled data showed a significantly better performance in margins of bur-prepared cavities in comparison to laser-prepared ones (Fig. 2, Mann-Whitney U Test, p=0.000).

After loading, statistical analysis of pooled data showed, once again, a significantly better performance in margins of bur-prepared cavities in comparison to laser-prepared ones (Fig. 3, Mann-Whitney U Test, p=0.013).

Effect of materials (comparison between the 6 groups)

When comparing the groups before loading (Fig. 4), the lowest scores of marginal adaptation were observed in group 4 (extra low shrinking adhesive (ELS adh) + hybrid composite (Clearfil Majesty). Significant differences were only observed between group 4 and the other five groups. The rest of the differences between groups were not significant, with %CM above 80%.

After loading (Fig. 5), the lowest scores of marginal adaptation were observed in group 4 (extra low shrinking adhesive (ELS adh) + hybrid composite (Clearfil cpr)) but also in group 1 (extra low shrinking adhesive (ELS adh) + extra low shrinking composite (ELS cpr)). %CM in these two groups were below 50%, which means that more than half of the marginal segments presented gaps. The differences between the other four groups were not significant, with the highest %CM above 80% in groups 3 (the positive control and 6.

Effectiveness of one-component adhesives in respect to the positive control Clearfil SE Bond (Gr 3)

Both before and after loading, a similar effectiveness was observed in the three one bottle adhesives (Allbond, experimental adhesive and Prime & Bond active) and the positive control, the 2-step self-etching adhesive Clearfil SE Bond.

Representative SEM micrographs of continuous margins and marginal openings, as visualized during the quantitative margin analysis, are shown in Fig. 6 and 7. In general, the margins of laser-prepared restorations presented broken / open margins or irregular shapes (Figure 8). Bur-prepared restorations presented regular margins, especially in the control group in which Clearfil SE Bond was used as the adhesive system (Fig. 7, E,F) and in the group restored with the universal adhesive prime & Bond active (Fig. 7, G,H).

DISCUSSION

In an attempt to find a cost-effective technique for restorative dentistry, the combination of laser technology together with simplified adhesives was compared to conventional restorative procedures. In this sense, this study investigated the effect of dental laser on the marginal adaptation of class V restorations with margins located on enamel and dentin by using the latest generation of one component adhesive systems in comparison to bur-drilled cavities, before and after a fatigue test consisting of mechanical and thermal stresses, under the influence of dentinal fluid simulation. The null hypotheses were that 1. There would not be a significant difference between laser and bur prepared groups and 2. There would not be any significant difference between the one-bottle adhesives and the positive control. In view of the results of this study the null hypothesis 1 had to be rejected, while null hypothesis 2 had to be partially accepted. Explanations to these findings will be provided in the next paragraphs.

Marginal adaptation was evaluated on class V cavities due to the favorable configuration of the cavity (C-factor) to test adhesion (Dalkilic et al. 2012, Heintze et al. 2007). Moreover, class V cavities can be easily standardized to avoid the potential of variability among practitioners. Marginal adaptation and integriity are clinically relevant methods to evaluate the quality of an adhesive system, because marginal microleakage can result in the failure of restoration, being also considered as a predominant cause of secondary caries (Dalkilic et al. 2012, Heintze et al. 2007). Thermo-mechanical loading was used to simulate the oral environment. Scanning Election Microscope (SEM) evaluation based on replicas is beneficial for evaluating cavities preparation both in vitro and in vivo. This method does not cause damage on the sample, enabling to measure marginal adaptation before and after loading. Moreover, it enables a truly quantitative evaluation, since the margin quality is quantified as percentages of “continuous margin” ranging from 0 to 100%.

We used four different one bottle universal self-etch adhesive systems. Universal type or multi-mode one-step-self-etch adhesive systems have experienced a tremendous development in recent years. These adhesives are multi-purpose since they can be used with both adhesive techniques, etch and rinse and self-etch. By combining both characteristics of hydrophilic and hydrophobic in a low viscous compound, they are blended into single application (Hanabusa et al. 2012). Furthermore, this technique avoids the shortcoming of separate etching that may cause over-wetting or over-drying of dentin substrate, leading to instability of the bonding quality (Marchesi et al. 2014). Clearfil SE Bond, a two-step self-etch adhesive, served as the positive control since previous studies used it as a gold standard for the comparison between adhesive systems (Van Landuyt et al. 2007). This adhesive has been tested after 8-years of clinical service and repeatedly used in *in vitro* experiments due to its relatively mild pH, the presence of the acidic monomer 10-Methacryloyloxydecyl dihydrogen phosphate (10-MDP) in the first bottle, and the presence of a hydrophobic coat in the second bottle (Sadek et al. 2008, Sezinando 2014). When cavity preparation was performed with dental burs, group 1 (low shrinking adhesive Unibond ELS and low shrinking ELS composite resin) and group 4 (low shrinking adhesive Unibond ELS and conventional hybrid composite Clearfil Majesty) had the lowest percentage of marginal adaptation after loading in respect to the positive control (Gr 3: Clearfil SE Bond 2 and hybrid composite Clearfil Majesty). Unibond ELS is a material without HEMA (2-hydroxyethyl methacrylate), this monomer is also absent from ELS composite. HEMA is a low-molecular weight monomer and claimed as one important component in self-etch adhesive systems due to its function as co-solvent, which is able to diminish the separation phase of monomers (Van Landuyt et al. 2005). HEMA has been incorporated to adhesive systems to preserve their hydrophilicity. Despite of its controversy, in terms of potential allergenic effects, HEMA monomer is advantageous for adhesive systems since it facilitates the penetration of hydrophobic components into wet and demineralized dentin (Zanchi et al. 2010, Van Landuyt et al. 2008). Previous studies mentioned that adding 10% of HEMA into the adhesive system would increase the strength bond of one step self-etch adhesives (Van Landuyt et al. 2008). Felizardo et al (2011) in their study concluded that small amounts of HEMA would provide a good bond strength related to its ability in averting the phase separation, even though it is material dependent. Presumably, our low results of marginal adaptation with this HEMA-free adhesive might be explained by the missing effect of HEMA, that might have limited the penetration of the adhesive into the hybrid layer, generating adhesive failures that ended in marginal openings

Meanwhile, group 4 with the same adhesive system and different composite (low shrinking adhesive Unibond ELS and conventional hybrid composite Clearfil Majesty), showed slightly better results than group 1 (Fig. 5). In group 4 ELS Unibond adhesive system was combined with a nano-hybrid composite. It consists of prepolymerized organic fillers with 78% wt and 66% per volume. The prepolymerized filler particles are created by mixing organic polymerizable resin and an inorganic filler then curing them. Their function is to reduce shrinkage stresses during polymerization. Furthermore, it has a function in providing a composite with better characteristics due to its less viscosity, rendering the material easier to manipulate during treatment (Pratap et al. 2019). It is possible that less contraction forces might have been exerted on the cavity walls, favoring marginal adaptation and explaining with the percentages of continuous margins were higher in this group.

On the other hand, group 3 used as the positive control (Clearfil SE Bond) showed amongst the highest percentages of marginal closure in both laser and bur-prepared cavities. Based on its chemical composition, not only it contains the acidic monomer 10-MDP, but it has a long carbonyl chain consisting of two tails, one is a hydrophobic methacrylate group, which is able to chemically bond to methacrylate-based restoratives and cements, and the other one is a hydrophilic polar phosphate group capable of bonding to dental tissues, metals and zirconia through chemical reaction (Alex 2015). Moreover, the hydrophobic characteristic tends to be relatively stable in solution promoting a more durable shelf-life (Van Landuyt et al. 2008). In addition, MDP-10 is claimed as the most hydrophobic functional monomers in the adhesive system which is important for durability and stability in a bonding material since hydrolytic breakdowns on the interface area and water permeability are the main factors in failure of bonding (Fukegawa et al. 2006). Furthermore, MDP-10 which is a group of phosphoric ester, is able to bond chemically to the dental hard tissue through a switching process between its phosphate groups and phosphate groups of hydroxyapatite (HA) forming a stable and insoluble calcium-salts, this process is expained by “adhesion–decalcification” concept (Yoshioka et al. 2002, Giannini et al. 2015, Yoshida et al. 2004). This stable and insoluble MDP-calcium salts are then stored in self-assembled nano-layers (Yoshida et al.2012, Yoshihara et al. 2011). The combination between its nature of hydrophobic from MDP-10 and this chemical interaction are likely being a reason why this adhesive system can work efficiently to overcome the biodegradation and enhance the durability by protecting the collagen fibrils (Yoshida et al. 2012, Alex 2015). In the context of our study, Gr 3 with this material attained, both before and after loading, a median %CM of around 85% (Figures 6 and 7), demonstrating the stability of the adhesive interface against fatigue.

Similarly, group 6 had a high percentage of marginal adaptation (higher than 80%) both with conventional drill and lasers. These results might be related to its components, MDP-10 and dipentaerythritol pentacrylate phosphate (PENTA). These monomers are combined to reach pH 2.5 thus this adhesive system is considered as a mild-etch type. “Mild” type partially dissolves the smear layer creating a thin hybrid layer which is advantageous to promote chemical bond between dental substrate and functional monomers (Yoshida et al. 2004). Furthermore, the PENTA molecule is beneficial since it has a hydrophilic core and five double-bonds per molecule, hence it not only effectively works as a crosslinker but also works as a powerful wetting-aid (Yoshihara et al. 2011).

Finally, in this study yttrium aluminum garnet crystal laser (Er:YAG) was used with a pulse energy of 250 mJ and the wall of the cavity was finished/smoothed with a pulse energy of 150 mJ, in agreement with a previous study showing that lasers with energy over 300 mJ should be avoided as they may lead to damaged, fractured and cracked tissue surface (Rizcalla et al. 2012). Finishing procedure after cavity preparation is needed by using relatively high energy settings but lower than for cavity preparation, similar to what occurs with conventional drills when cavities are finished by fine diamond burs (Bader & Krejci 2006). Previous studies showed that lasers used with a maximum pulse energy of 300 mJ can provide similar results as conventional drills (Bader & Krejci 2006, Lizarelli et al. 2003, Bortolotto et al. 2017, Nerushay et al. 2019). Contrary to our study, no difference between conventional drills and lasers has been observed in terms of micro-leakage of composite restoration (Mossadik et al. 1999). Er:YAG lasers work through micro-explosions that are mechanically related to water vaporization, thus it behaves different to drilling with diamond bur while applied to the enamel structure, which is brittle and may easily fracture when subjected to laser micro-explosions (Bader & Krejci 2006). The lower performance of laser in respect to bur-preparation observed in the present study was probably due to the use of a high pulse duration, which was of 150 µs. Most probably, this long interaction time with the irradiated tissue resulted in a temperature rise that could have affected its microstructure and bonding ability (Nerushay et al. 2019). In this sense, further studies might be necessary with lasers using lower pulse duration less than 110 µs (Nerushay et al. 2019) to determine the effect of this variable on marginal adaptation.

Conclusions

Based on the results and within the limitations of this *in vitro* study, the following conclusions can be drawn:

- The restorations prepared by laser showed lower marginal adaptation compared to bur-drilled ones. The use of a high pulse duration might be a plausible explanation for these lower results.
- The cavity margins prepared by laser showed an irregular shape on enamel and dentin margins when compared to more regularly shaped bur-prepared margins.
- The gold-standard 2-step self-etching adhesive (Clearfil SE Bond) attained the highest % of marginal adaptation together with two universal adhesives. This indicates that one-bottle simplified universal adhesives can be as effective as multi-bottle ones. The specific chemical composition of each adhesive appears to be the major factor affecting their effectiveness.

REFERENCES

Abdulsamee N. All Tissues Dental Laser Er:YAG laser- Review Article. Biomed J Sci-Fi & Tech 2017; 1(1): 9-17

Alex G. Universal Adhesives: The Next Evolution in Adhesive Dentistry? Compend Contin Educ Dent actions 2015; 36(1): 15-26

Aranha AC, Eduardo CP, Gutknecht N, Marques MM, Ramalho, KM, Apel C. Analysis of the interfacial micro- morphology of adhesive systems in cavities prepared with Er,Cr:YSGG, Er:YAG laser and bur. Microsc Res Tech 2007; 70: 745–751

Bader, Krejci I. Indications and limitations of Er:YAG laser applications in dentistry. Am J Dent 2006; 19: 78-186

Bedran-de-Castro AK, Pereira PN, Pimenta LA, Thompson JY. Effect of thermal and mechanical load cycling on microtensile bond strength of a total-etch adhesive system. Oper Dent 2004; 29(2): 150–6

Benetti AR, Peutzfeldt A, Lussi A. Flury S. Resin composite: Modulus of elasticity and marginal quality. J Dent 2014; 42: 185-1192

Black GV. A work on operative dentistry: The technical procedures in filling teeth. Chicago: Medico-Dental Publishing House. 1917; 25: 111–19

Bortolotto T, Betancourt F, Krejci I. Marginal integrity of resin composite restorations restored with PPD initiator- containing resin composite cured by QTH, monowave and polywave LED units. Dent Material J 2016; 35(6): 869-875

Bortolotto T, Mast P, Krejci I. Laser-prepared and bonding-filled fissure sealing: SEM and OCT analysis of marginal and internal adaptation. Dent Mater J 2016; 36: 622-629

Buonocore MG. A simple method of increasing the adhesion of acrylic filling to enamel surfaces. J Dent Res 1955; 34(6): 849-853

Buonocore MG, Matsui A, Gwinnett AJ. Penetration of resin dental materials into enamel surfaces with reference to bonding. Arch Oral Biol 1968; 13: 61-70

Camps J, Pashley DH. Buffering action of human dentin in vitro. J Adhes Dent 2000; 2(1): 39-50

Cardoso MV, de Almeida Neves A, Mine A, Coutinho E, Van Landuyt K, De Munck J, Van Meerbek B. Current aspects on bonding effectiveness and stability in adhesive dentistry. Austr Dent J 2011; 56:(1): 31–44

Carvalho AO, Reis AF de Oliveira MT, de Freitas PM, Aranha AC, Eduardo CD, Giannini M. Bond Strength of Adhesive Systems to Er,Cr:YSGG Laser- Irradiated Dentin. Photomed Laser Surg 2011; 29(11): 747-52

Carvalho RM, Chersoni S, Frankenberger R, Pashley DH, Prati C, Tay FR. A challenge to the conventional wisdom that simultaneous etching and resin infiltration always occurs in self-etch adhesives. Biomaterials 2005; 26: 1035–1042

Dalkilic E, Omurlu H. Two-year clinical evaluation of three adhesive systems in non-carious cervical lesions. J Appl Oral Sci 2012; 20: 192-199

De Munck J, Van Meerbeek B, Yudhira R, Lambrechts P, Vanherle G. Microtensile bond strength of two Erbium:YAG-lased vs. bur-cut enamel and dentin. Euro J Oral Sci 2002; 110: 322–329

De Munck J, Van Meerbeek B, Vargas M. One day bonding effectiveness of new self-etch adhesives to bur-cut enamel and dentin. Oper Dent 2005; 30: 39–49

Diaci J. Laser Profilometry for the Characterization of Craters Produced in Hard Dental Tissues by Er:YAG and Er,Cr:YSGG Lasers. J LA&HA 2008; 6(2): 1- 11

Diaci J, Gaspirc B. REVIEW; Comparison of Er:YAG and Er,Cr:YSGG lasers used in dentistry. J LA&HA 2012; 1: 1-13

Ericskson D, Kidd E, MC Comb, MJör I, Noack MJ. Minimally invasive dentistry- concept and techniques in cariology. Oral Health Prev Dent 2003; 1(1): 59-72

Felizardo KR, Lemos LVFM, Carvalho RV, Junior AG, Lopes MB, Moura SK. Bond strength of HEMA-containing versus HEMA-free self-etch adhesive systems to dentin. Braz Dent J 2011; 22: 468-472

Frankenberger R, Tay FR. Self-etch vs etch-and- rinse adhesives: effect of thermo-mechanical fatigue loading on marginal quality of bonded resin composite restorations. Dent Mater 2005; 21(5): 397-412

Fukegawa D, Hayakawa S, Yoshida Y. Chemical interaction of phos- phoric acid ester with hydroxyapatite. J Dent Res 2006; 85(10): 941-944

Fusayama T. The problems preventing progress in adhesive dentistry. Adv Dent Res 1988; 2(1): 158-161

Giannini M, Makishi P, Ayres APA, Vermelho PM, Fronza BM, Nikaido T, Tagami J. Self-Etch Adhesive Systems: A Literature Review. Braz. Dent. J 2015; 26(1):3-10

Gökçe, B. Özpinar, M. Dündar, E. Çömlekoglu, B. H. Sen, and M. A. Güngör. Bond Strengths of All-Ceramics: Acid vs Laser Etching. Oper Dent 2017; 32(2): 173-178

Harashima T, Kinoshita J, Kimura Y, Brugnera A, Zanin F, Pecora JD, Matsumoto K. Morphological comparative study on ablation of dental hard tissues at cavity prep ration by Er:YAG and Er,Cr:YSGG lasers. Photomed Laser Surg 2005; 23(1): 52-5

Hanabusa M, Mine A, Kuboki T, Momoi Y, Van Ende A, Van Meerbeek B, De Munck J. Bonding effectiveness of a new 'multi-mode' adhesive to enamel and dentine. J Dent 2012; 40(6): 475-84

Heintze SD. Systematic reviews: I. The correlation between laboratory tests on marginal quality and bond strength. II. The correlation between marginal quality and clinical outcome. J Adhes Dent 2007; 9: 77-106

Hibst R. Lasers for caries removal and cavity preparation: State of the art and future directions. J Oral Laser Appl 2002; 2: 203-212

Jingarwar MM., Bajwa NK, Pathak A. Minimal Intervention Dentistry- A new Frontier in a clinical Dentistry. Journal of Clinical and Diagnostic Research: JCDR 2014; 8(7): ZE04-ZE08

Khoroushi M, Etemadi S, Kheir MK. Marginal Leakage of Class V Composite Resin Restorations. Dent Hypotheses 2018; 9: 11-15

Korkmaz FM, Baygin O, Arslan I. The effect of an erbium, chromium: yttrium-scandium-gallium-garnet laser on the microleakage and bond strength of silorane and micro-hybrid composite restorations. Eur J Dent 2013; 7(1): S33-40

Koyoturk AE, Kusgoz A, Ulker M, Yesilyurt C. Effects of mechanical and therma aging on microleakage of different ssure sealants. Dent Mater J 2008; 27(6): 795-801

Krejci I, Simunovic K, Lutz F. Substance removal with a super pulsed CO2-laser. Schweiz Monatsschr Zahnmed 1992; 102: 693-699

Lizarelli R de F, Moriyama LT, Bagnato VS. Ablation of composite resins using Er:YAG laser. Comparison with enamel and dentin. Lasers Surg Med 2003; 33: 132-139

Lutz, Krejci I, Barbakow F. Quality and durability of marginal adaptation in bonded composite restorations. Dent Mater J 1991; 7(2): 107-113

Lopes MB, Yan Z, Consani S, Júnior AG, Aleixo A, McCabe JF. Evaluation of the coefficient of thermal expansion of human and bovine dentin by thermomechanical analysis. Braz Dent J 2012; 23(1): 3-7

Marchesi G, Frassetto A, Mazzoni A, Apolonio F, Diolosa M, Cadenaro M. Adhesive performance of a multi-mode adhesive system: 1-year in vitro study. J Dent 2014; 42(5): 603-12

Mclean JW, Kramer IRH. A clinical and pathological evaluation of a sulphinic acid-activated resin for use in restorative dentistry. Braz Dent J. 1952; 93: 255–269

Monteiro GQ, Montes MA, Gomes AS, Mota CC, Campello SL, Freitas AZ. Marginal analysis of resin composite restorative systems using optical coherence tomography. Dent Mater J 2011; 27: 213–223

Mossadik H, Nakamura Y, Yamada Y. Ablation depths and morphological changes in human enamel and dentin after Er:YAG laser irradiation with or without water mist. J Clin Laser Med Surg 1999; 17(3): 105-9

Moszner, Norbert, Salz, Ulrich, Zimmermann, Jörg. Chemical aspects of self-etching enamel-dentin adhesives : A systematic review. Dent Mater 2005; 21: 895–910

Nagem HF, Nagem HD, Francisconi PA, Franco EB, Mondelli RF, Coutinho KQ. Volumetric polymerization shrinkage of contemporary composite resins. J Appl Oral Sci 2007; 15: 448-52

Neppelenbroe KH. The clinical challenge of achieving marginal adaptation in direct and indirect restorations. J Appl Oral Sci 2015; 23: 448–449

Nerushay I, Krejci I, Ryabova A, Bortolotto T. Influence of pulse duration when performing Er:YAG laser irradiation on dental tissues. Am J Dent 2019; 32: 61-68

Nikaido T, Kunzelmann KH, Chen H, Ogata M, Harada N, Yamaguchi S, Cox CF, Hickel R, Tagami J. Evaluation of thermal cycling and mechanical loading on bond strength of a self-etching primer system to dentin. Dent Mater J 2002; 18(3): 269-275

Papadogiannis D, Kakaboura A, Palaghias G, Eliades G. Setting characteristics and cavity adaptation of low-shrinking resin composites. Dent Mater J 2009; 25: 1509-16

Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B. Clinical effectiveness of contemporary adhesives: a systematic review of current clinical trials. Dent Mater J 2005; 21: 864-881

Peumans M, De Munck J, Van Landuyt KL, Poitevin A, Lambrechts P, Van Meerbeek B. Eight-year clinical evalution of a two-step self-etch adhesive with and without selective enamel etching. Dent Mater J 2010; 26: 1176–1184

Pratap B, Gupta RK, Naag M. Resin based restorative dental materials: characteristics and future perspectives. Jpn Dent Sci Rev 2019; 55(1): 126-138

Punithia PG, Shashikala K. Evaluation of the adaptation of resin based sealers epiphany, AH plus and AH 26 to the root canal dentin by scanning electron microscope. Indian J Stomatol 2011; 2: 207-11

Ramos AC, Esteves-Oliveira M, Arana-Chavez VE, De Paula Eduardo C. Adhesives bonded to erbium:yttrium–aluminum–garnet laser-irradiated dentin: transmission electron microscopy, scanning electron microscopy and tensile bond strength analyses. Lasers med Sci 2010; 25(2): 181–189

Reis A, Bedran R, Gianini M, Pereira P. Interfacial ultramorphology of single-step adhesives: nanoleakage as a function of time. J Oral Rehabil 2007; 34: 213-221

Rengo C, Goracci C ,Ametrano G, Chieffi N, Spagnuolo G, Rengo S, Ferrari M. Marginal Leakage of Class V Composite Restorations Assessed Using Microcomputed Tomography and Scanning Electron Microscope. Oper Dent J 2015; 40(4): 440-448

Rizcalla N, Bader C, Bortolotto T, Krejci I. Improving the efficiency of an Er: YAG laser on enamel and dentin. Quintessence Int 2012; 42: 153-160

Rodrigues SA Jr, Pin LF, Machado G, Della Bona A, Demarco FF. Influence of different restorative techniques on the marginal seal of class II composite restorations. J Appl Oral Sci 2010; 18: 37-43

Rodriguez SA JR, Zanchi CH, Carvalho RV, Demarco FF. Flexural strength and modulus of elasticity of different types of resin-based composites. Braz Oral Res 2007; 21(1): 16-21

Sadek FT, Calheiros FC, Cardoso PE, Kawano Y, Tay F, Ferrari M. Early and 24-hours bond strength and degree of conversion etch and rinse and self-etch-adhesive. Am J Dent 2008; 21: 30–34

Sasaki, LH.; Lobo, PD.; Moriyama, Y.; Watanabe, IS.; Villaverde, AB.; Tanaka, CS.; Moriyama, EH. & Brugnera A, Jr. Tensile bond strength and SEM analysis of enamel etched with Er:YAG laser and phosphoric acid: a comparative study in vitro. Braz Dent J 2008; 19(1): 57-61

Sensi L, Marson FB, Belli R, Baratieri LN, Monteiro S Jr. Interfacial morphology of self-etching adhesive systems in dentin. Quintessence Int. 2007; 38: e112-119

Sezinando A. Looking for the ideal adhesive – A review. Rev Port Estomatol med dent cir maxilofac 2014; 55(4): 194–206

Sidhu SK, Carrick TE, McCabe JF. Temperature mediated coefficient of dimensional change of dental tooth-colored restorative materials. Dent Mater J 2004; 20: 435-440

Söderholm KJ. Dental adhesives how it all started and later evolved. J Adhes Dent 2007; 9(2): 227–230

Sofan E, Sofan A, Gaspare P, Gianluca T, Umberto R, Guido M. Classification review of dental adhesive systems: from the IV generation to the universal type. Ann Stomatol (Roma) 2017; 8(1): 1-17

Sundfeld RH, Valentino TA, Alexandre RS, Briso ALF, Sun-defeld MLMM. Hybrid layer thickness and resin tag length of a self-etching adhesive bonded to sound dentin. J Dent 2005; 33: 675–681

Tay DH, Pashley. Aggressiveness of contemporary self-etching systems I: depth of penetration beyond dentin smear layers. Dent Mater J 2001; 17: 296-308

Van As G. Erbium lasers in dentistry. Dent Clin N An 2004; 48: 1017-1059

Van Landuyt KL, Snauwaert J, Peumans M, De Munck J, Lambrechts P, Van Meerbeek B. The role of HEMA in one-step self-etch adhesives. Dent Mater J 2008; 24: 1412–1419

Van Landuyt KL, De Munck J, Snauwaert J, Coutinho E, Poitevin A, Yoshida Y, Inoue S, Peumans M, Suzuki K, Lamberchts P, Van Merbeek B. Monomer-solvent phase separation in one-step self-etch adhesives. J Dent Res 2005; 84: 183–188

Van Landuyt KL, Snauwaert J, De munck J, Peumans M, Yoshida Y, Poitevin A, Coutinho E, Suzuki K, Lambrechts P, Van Merbeek B. Systematic review of th chemical composition of contemporary dental adhesives. Biomaterials 2007; 28: 3757–85

Van Landuyt KL, Yoshida Y, Hirata I, Snauwert J, De Munck J, Okazaki M, Suzuki K, Lambercht P, Van Merbeek B. Infuence of the chemical structure of functional monomers on their adhesive performance. J Dent Res 2008; 87(8): 757-761

Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P. Adhesion to enamel and dentin: currents status and future challenges. Oper Dent 2003; 28: 215-235

Van Meerbeek B, Van Landuyt K, De Munck J, Inoue S, Yoshida Y, Perdiago J, Lambrechts P, Peumans M. BONDING TO ENAMEL. Fundamentals of Operative Dentistry. A Contemporary Approach. 3rd edn. Chicago: Quintessence Publishing 2006; 183–260

Van Meerbeek B, Yoshihara K, Yoshida Y, Mine A, De Munck J, Van Landuyt, K.L. State of the art of self-etch adhesives. Dent Mater J 2011; 27: 17-28

Xu HHK, Smith DT, Jahanmir S, Romberg E, Kelly JR, Thompson VP, Rekow ED. Indentation damage and mechanical properties of human enamel and dentin. J Dent Res 1998; 77(3): 472-80

Yan Z, Sidhu SK, Carrick TE, McCabe JF. Response to thermal stimuli of glass ionomer cements. Dent Mater J 2007; 23: 597-600

Yoshida Y, Van Meerbeek B, Nakayama Y, Snauwaert J, Hellemans L, Lambrechts P, Vanherle G, Wakasa K.Evidence of chemical bonding at biomaterial–hard tissue interfaces. J Dent Res 2000; 79: 709-714

Yoshida Y, Nagakane K, Fukuda R, Nakayama Y, Okazaki M, Shintani H, Inoue S, Tagawa Y, Suzuki K, De Munck J, Van Merbeek B. Comparative study on adhesive performance of functional monomers. J Dent Res 2004; 83: 454–458

Yoshida Y, Yoshihara K, Nagaoka N, Hayakawa S, Torii Y, Ogawa T, Osaka A, Van Merbeek B. Self-assembled Nano-layering at the Adhesive interface. J Dent Res 2012; 91(4): 376-381

Yoshioka M, Yoshida Y, Inoue S, Lambrechts P, Vanherle G, Nomura Y, Okazaki K, Shintani H, Van Merbeek B. Adhesion/decalcification mechanisms of acid interactions with human hard tissues. J Biomed Mater Res 2002; 59: 56–62

Yoshihara K, Yoshida Y, Hayakawa S, Nagaoka N, Irie M, Ogawa T, Van Landuyt KL, Osaka A, Suzuki K, Minagi S, Van Meerbeek B. Nanolayering of phosphoric acid ester monomer on enamel and dentin. Acta Biomater 2011; 7: 3187-3195

Zanchi CH, Munchow EA, Ogliari FA, Chersoni S, Prati C, Demarco FF, Piva E.Development of experimental HEMA-free-three-step adhesive system. J Dent 2010; 38: 503-508

TABLE 1. Description of the materials used on each group.

Group	Materials Adhesive / Composite resin	LOT	Components
1	**Unibond ELS (SAREMCO, Rebstein, Switzerland) **ELS composite dental shade A2 (SAREMCO, Rebstein, Switzerland)	C778 C731	**Adhesive:** ethanol, water, ethoxylated Bis-GMA, phosphoric acid methacrylate, initiators. HEMA-free and TEGDMA-free **Composite resin**: micro hybrid, free of TEGDMA and HEMA
2	All Bond Universal adhesive system (BISCO, Illinois, USA) Clearfil Majesty ES-2 classic shade A2 (Kuraray Noritake, Kuraishi, Japan)	160000289 7U0043	**Adhesive:** 10-MDP, Bis-GMA, HEMA, ethanol, water, initiators **Composite resin**: Dimethacrylate resins, HEMA, Ethanol, Water, Silane, Fillers, Initiators
3	Clearfil SE Bond 2 (Kuraray Noritake, Kuraishi, Japan) Clearfil Majesty ES-2 classic shade A2 (Kuraray Noritake, Kuraishi, Japan)	2J0135 7U0043	**Adhesive: Primer:** 10-MDP, HEMA, hydrophilic DMA, photo-initiator, aromatic tertiary amine, water. **Bonding:** 10-MDP; Bis-GMA, HEMA, Hydrophobic DMA, photo-initiator, aromatic tertiary amine, silanated colloidal silica **Composite resin**: Dimethacrylate resins, HEMA, Ethanol, Water, Silane, Fillers, Initiators

4	**Unibond ELS (SAREMCO, Rebstein, Switzerland) Clearfil Majesty ES-2 classic shade A2 (Kuraray Noritake, Kuraishi, Japan)	C778 7U0043	**Adhesive:** ethanol, water, ethoxylated Bis-GMA, phosphoric acid methacrylate, initiators. HEMA-free and TEGDMA-free **Composite resin**: Dimethacrylate resins, HEMA, Ethanol, Water, Silane, Fillers, Initiators
5	Kuraray adhesive system SKB-100 (Kuraray Noritake, Kuraishi, Japan) Clearfil Majesty ES-2 classic shade A2 (Kuraray Noritake, Kuraishi,Japan)	T160128 7U0043	**Adhesive:** Not disclosed by manufacturer **Composite resin**: Dimethacrylate resins, HEMA, Ethanol, Water, Silane, Fillers, Initiators
6	Prime & Bond Active universal adhesive system, (DENTSPLY, New York, US) Clearfil Majesty ES-2 classic shade A2 (Kuraray Noritake, Kuraishi,Japan)	160500400 7U0043	**Adhesive:** Bi-and multi-functional acrylate, phosphoric acid modified acrylate resin, initiator, stabilizer, isopropanol, water **Composite resin**: Dimethacrylate resins, HEMA, Ethanol, Water, Silane, Fillers, Initiators

**Unibond ELS and **ELS composite are bioholistic biomaterials manufactured by Saremco, a Swiss company that presents them as part of the Green Line range of products free of TEGDMA and HEMA.

TABLE 2. Description of the Er:YAG laser device used in the study and the parameters for cavity preparation.

Laser device (Pluser, doctor smile, LAMBDA SpA, Brendola, Italy)		
	On enamel	**On dentin**
Parameters for cavity preparation:		
Handpiece type	Boost type with non-touch tip	
Distance of laser tip from the surface (mm)	1mm	1mm
Emission wavelength (nm)	2940	2940
Power (Watts)	5	5
Pulse energy or power density (mJ)	250	250
Pulse frequency (Hz)	20	20
Pulse length or pulse duration (μs)	150	150
Air pressure (min 2.5 bar - max 8 bar)	100%	100%
Water flow rate	80%	80%
Parameters for cavity finishing:		
Handpiece type	Boost type with non-touch tip	
Distance of laser tip from the surface (mm)	1mm	1mm
Emission wavelength (nm)	2940	2940
Power (Watts)	3	3
Pulse energy or power density (mJ)	150	150

Pulse frequency (Hz)	20	20
Pulse length or pulse duration (µs)	150	150
Air pressure (min 2.5 bar – max 8 bar)	100%	100%
Water flow rate	60%	60%

FIGURE 1. Image of the laser used in this study (Pluser, doctor smile, LAMBDA SpA).

Source of image: https://healthmanagement.org/products/view/dental-laser-surgical-er-yag-on-trolley-2940-nm-10-w-pluser-doctor-smile

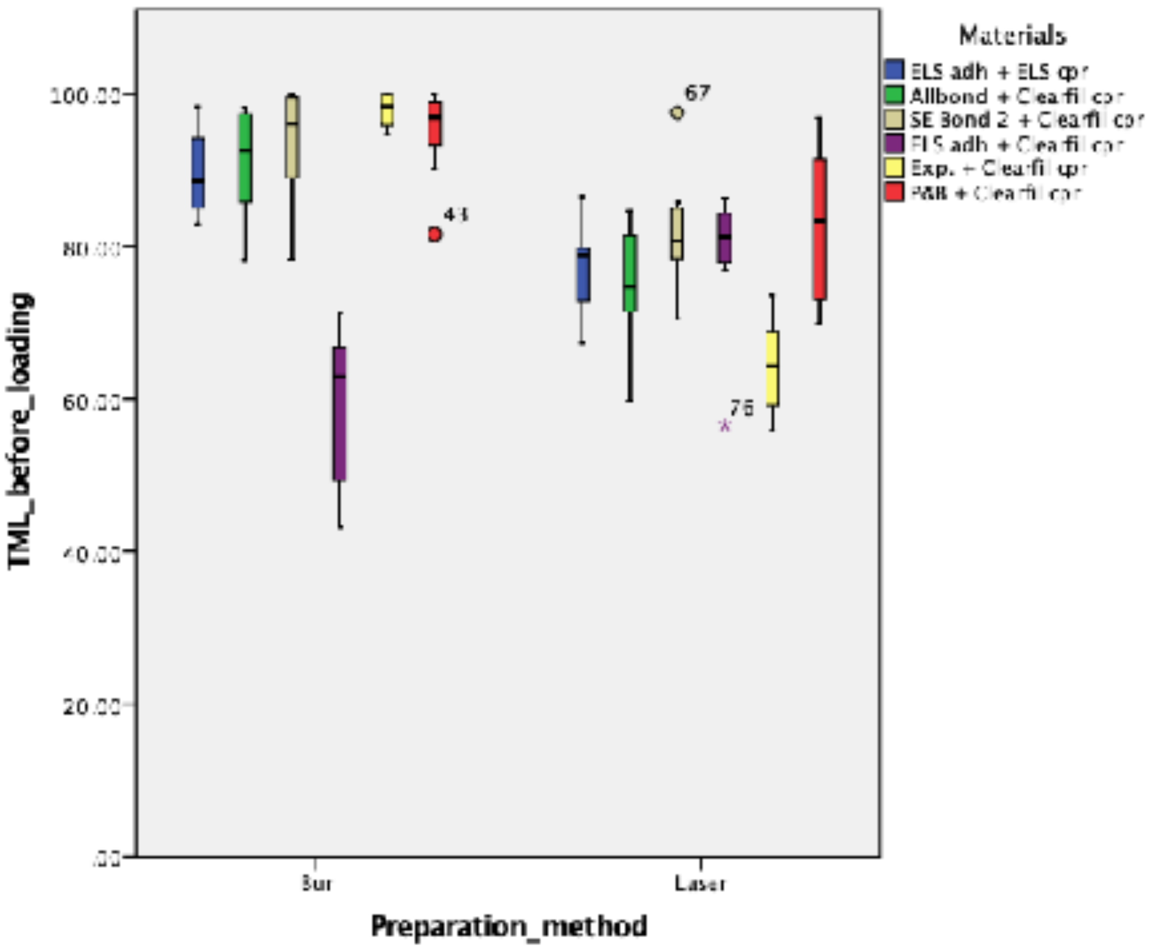

FIGURE 2. Overview of %CM at the Total Marginal Length <u>before loading</u> based on preparation method (laser and bur).

FIGURE 3. Overview of %CM at the Total Marginal Length <u>after loading</u> based on preparation method (laser and bur).

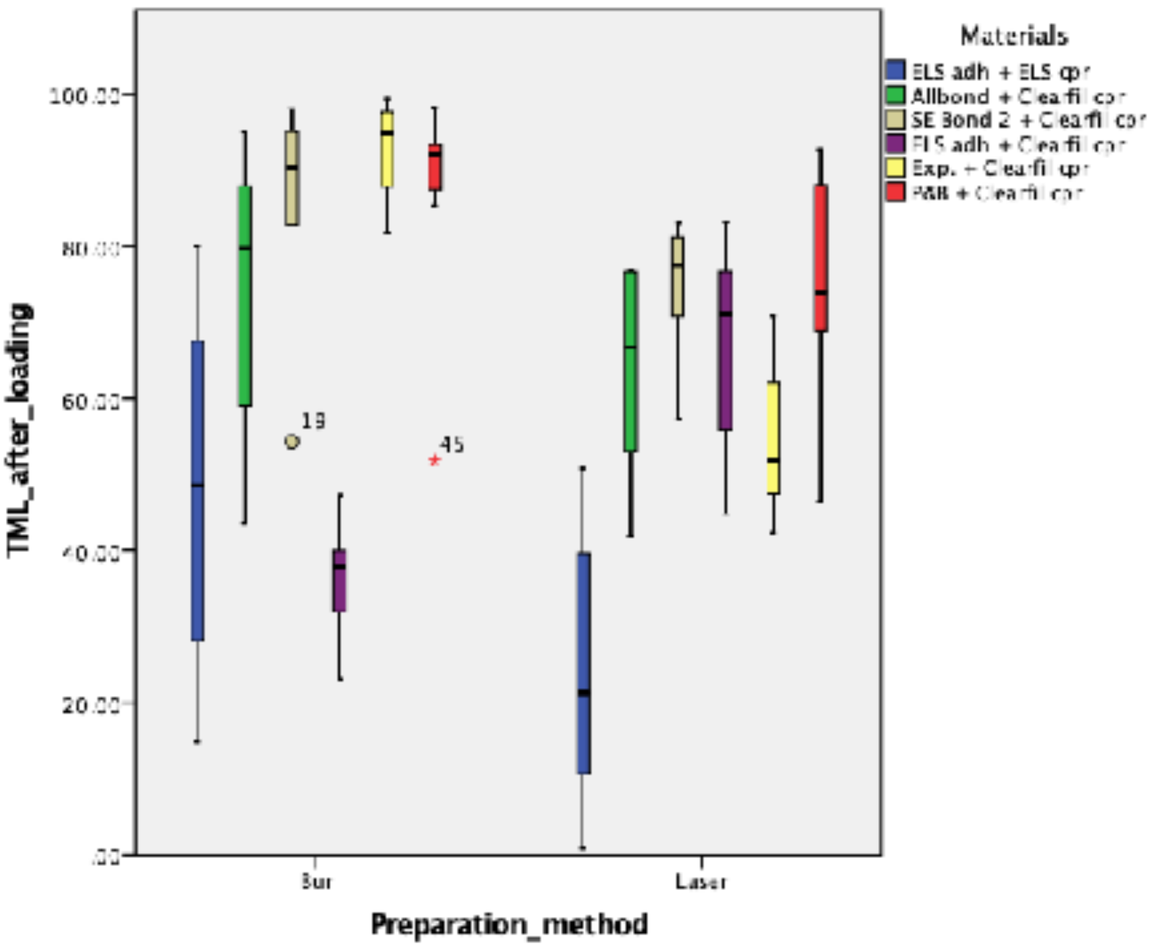

FIGURE 4. Percentages of continuous margins at the Total Margin Length before loading (initial) according to the group of materials. (Kruskal-Wallis and Duncan post-hoc test). Groups sharing the same letter are statistically similar at the p=0.05 level.

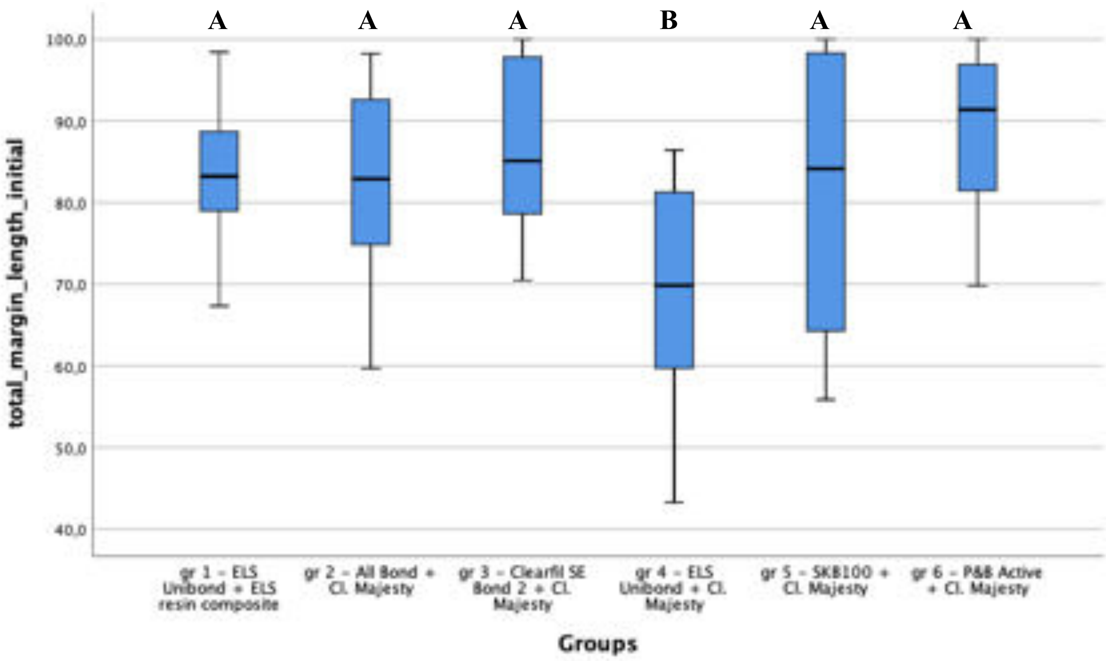

FIGURE 5. Percentages of continuous margins at the Total Margin Length after loading (terminal) according to the group of materials (Kruskal-Wallis and Duncan post-hoc test). Groups sharing the same letter are statistically similar at the p=0.05 level.

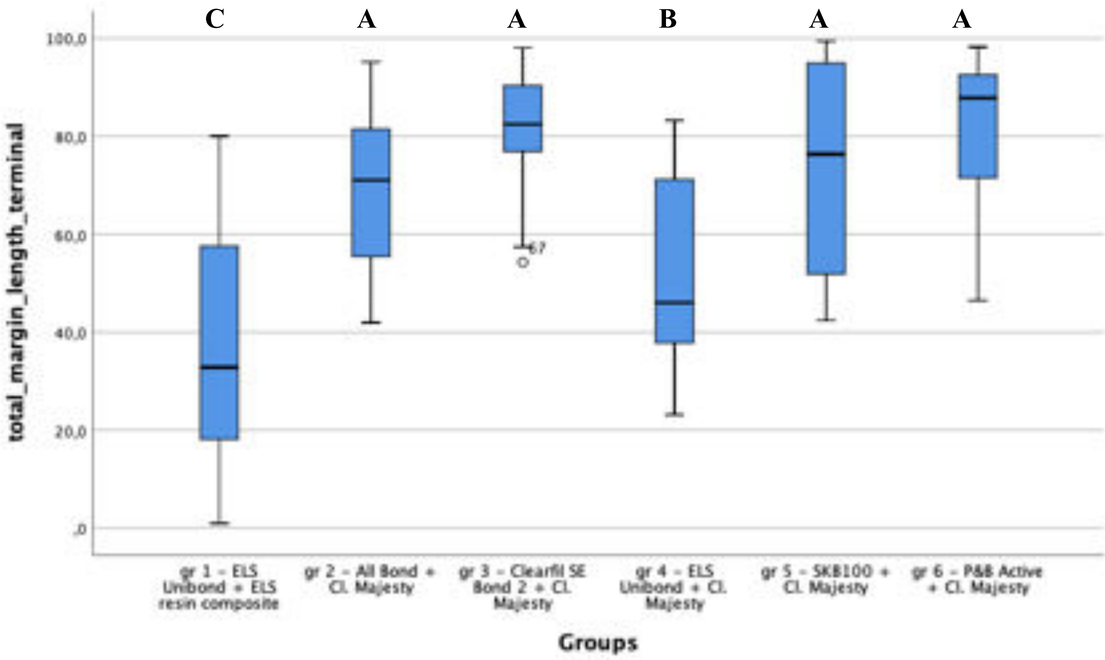

FIGURE 6. Representative SEM micrographs of non-continuous margins on enamel (A,C) and dentin (B,D) margins of laser-prepared restorations, observed after loading. Open margins (orange arrows) and irregular shapes (blue arrows) were the main characteristics observed at the margins of several groups prepared by laser.

A. group 1 (low-shrinking adhesive and composite) laser-prepared after loading on enamel;

B. group 1 (low-shrinking adhesive and composite) laser-prepared after loading on dentin, see the broken marginal on the surface of composite restoration;

C. group 4 (low-shrinking adhesive) laser-prepared after loading on enamel;

D. group 4 (low-shrinking adhesive) laser-prepared after loading on dentin see the irregular-shaped on the surface of composite restoration.

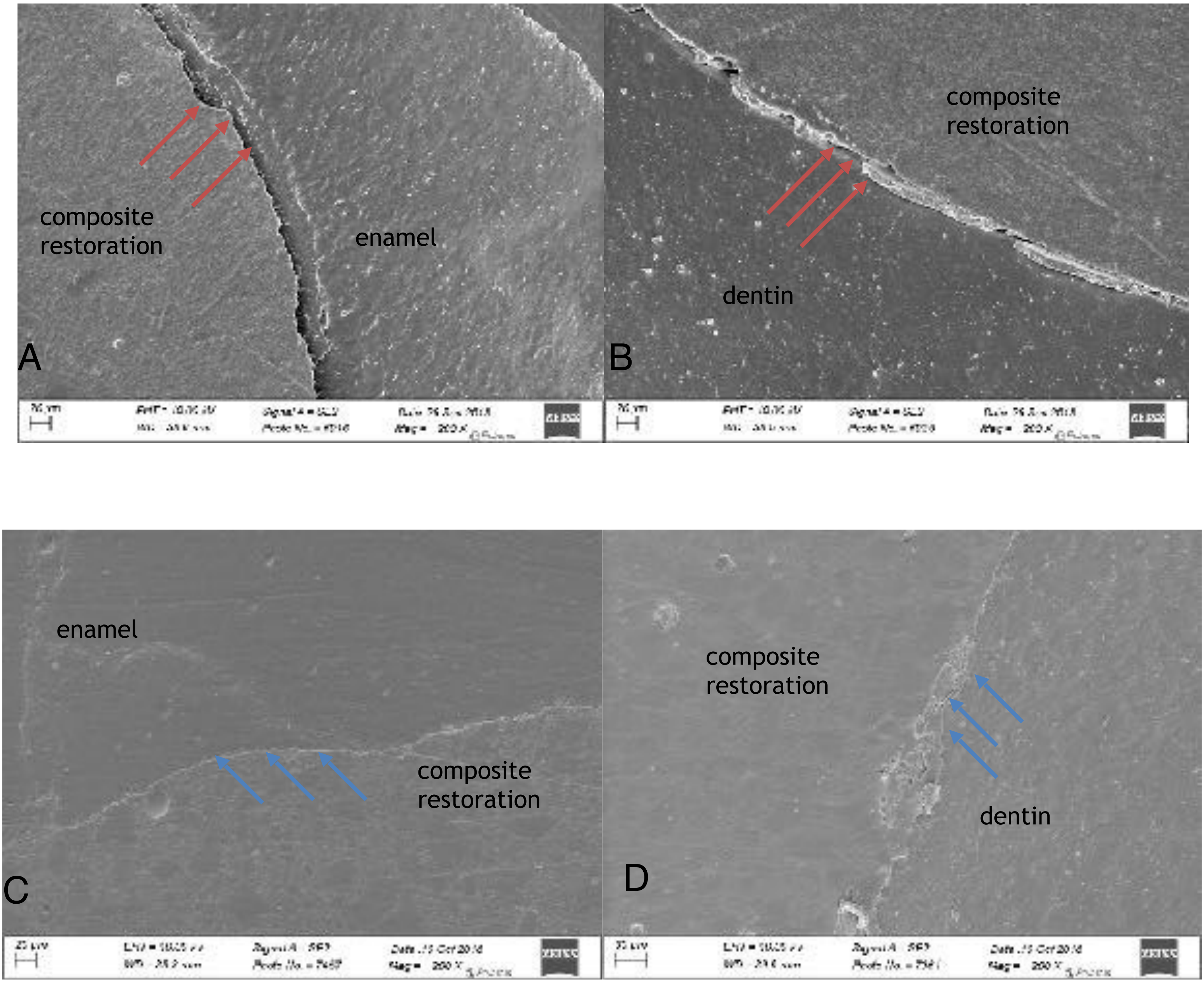

FIGURE 7. Representative SEM micrographs of continuous margins on enamel (E,G) and dentin (F,H) margins of bur-prepared restorations, observed after loading. See that restoration margins are smooth and precisely defined.

E. group 3 (Clearfil SE Bond, positive control) bur-prepared after loading on enamel;
F. group 3 (Clearfil SE Bond, positive control) bur-prepared after loading on dentin;
G. group 6 (universal adhesive Prime & Bond active) bur-prepared after loading on enamel;
H. group 6 (universal adhesive Prime & Bond active) bur-prepared after loading on dentin.