Universidade de Lisboa
Faculdade de Medicina Dentária

INFLUENCE OF THE TIMING OF SALIVA CONTAMINATION ON THE ADHESION TO ZIRCONIA

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Dissertação
Mestrado Integrado em Medicina Dentária

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In the memory of my grandmother

Who never had the opportunity to see what I've become…

I hope I made you proud.

Acknowledgements

"Remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist. Be curious. And however difficult life may seem, there is always something you can do and succeed at. It matters that you don't just give up."

Professor Stephen Hawking

In the light of these words, I would like to express my gratitude to the following individuals, without whom I would not have been able to accomplish this work:

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Abbreviations

Y-TZP	Yttria Tetragonal Zirconia Polycrystal
HF	Hydrofluoridric
APA	Airborne Particle Abrasion
10-MDP	10- Methacryloyloxydecyl Dihydrogen Phosphate
SBS	Shear Bond Strength

Abstract

Purpose: The purpose of the present study was to evaluate the ability to promote adhesion of two luting materials to saliva contaminated zirconia, according to the following null hypothesis: 1) the adhesive system does not influence bond strength to zirconia; 2) the timing of saliva contamination does not influence the bond strength to zirconia.

Materials and Methods: Sixty blocks of zirconia were randomly assigned to six experimental groups, according to the possible combinations between luting materials (OptiBond XTR + NX3 Nexus / Futurabond M+ + Bifix QM) and saliva contamination conditions (no contamination / contamination after the adhesive application / contamination prior to the adhesive application) (n=10). Previously polymerized composite disks were then seated onto the luting material and the set was light-cured, according to manufacturer's instructions. Specimens were then stored in distilled water at 37ºC for 48 hours. Shear bond strength (SBS) tests and failure mode analysis were performed. SBS data were analysed by two-way ANOVA, followed by Tukey-HSD post-hoc tests, and failure mode by Krustal-Wallis and Mann-Whitney tests (α=0.05).

Results: SBS mean values ranged from 12.2 MPa to 22.0 MPa. The groups subjected to no contamination or contamination prior to the adhesive system application yielded a significantly ($p<0.05$) higher SBS than the other contamination condition. The luting materials used did not statistically influence SBS ($p=0.187$). Failure mode was influenced by contamination conditions ($p=0.007$), but no difference was found between luting materials ($p=1.000$).

Conclusions: Despite the luting materials did not influence bond strength to zirconia, the timing of saliva contamination did. To rinse saliva contaminated zirconia surfaces seems to be an effective method for saliva decontamination. However, the adhesive system used combined with cements should be applied before try-in.

Keywords: Zirconia, Shear Strength, Saliva Contamination, Try-in, Adhesion.

Resumo

Ao longo das últimas décadas, grandes melhorias foram alcançadas no que diz respeito às propriedades mecânicas da cerâmica dentária. A introdução da zircónia como material dentário gerou um interesse considerável na comunidade médico-dentária, especialmente devido à sua excelente biocompatibilidade, força mecânica e à crescente procura por restaurações estéticas e livres de metal. Estas características deram à zircónia o potencial para ser aplicada como uma alternativa ao metal no fabrico de estruturas. Por esta razão, uma técnica adesiva é, frequentemente, desejável.

A adesão às cerâmicas tradicionais é um procedimento previsível com resultados duradouros. No entanto, a composição e as propriedades físicas da cerâmica de elevada resistência, como é o caso da zircónia, diferem substancialmente das tradicionais, razão pela qual o condicionamento com ácido fluorídrico não é eficaz, requerendo procedimentos alternativos para a obtenção de retenções micromecânicas. Apesar de não existir ainda um tratamento de superfície alternativo universalmente aceite, o jateamento com partículas suspensas de óxido de alumínio tem provas dadas quanto ao aumento da rugosidade de superfície, sendo o método preconizado para a criação de microretenções. Ainda, o facto de a zircónia não possuir sílica na sua constituição torna difícil o estabelecimento de uma adesão adequada a resinas compostas. Vários *primers* com monómeros fosfatados, como o 10-MDP, têm sido usados para o efeito.

Um obstáculo comum encontrado pelo clínico durante a adesão à zircónia é a sua contaminação com saliva durante os procedimentos de *try-in*, o que leva a uma diminuição da sua adesão ao cimento resinoso. A lavagem da cerâmica com *spray* de água corrente é o método de descontaminação mais simples e usado pelos médicos dentistas. Pelo facto de os resultados da descontaminação nem sempre serem satisfatórios, foi sugerida a aplicação do sistema adesivo na superfície da zircónia antes do *try-in*. No entanto, os efeitos deste procedimento não se encontram, ainda, bem documentados.

Objetivos: O objetivo do presente estudo foi avaliar a capacidade de promoção de adesão de dois materiais de cimentação a zircónia contaminada com saliva, sob condições de contaminação distintas. As hipóteses nulas testadas foram: 1) o sistema adesivo não tem influência sobre os valores de adesão à zircónia; 2) o momento de contaminação com saliva não tem influência sobre os valores de adesão à zircónia.

Materiais e métodos: Sessenta blocos de zircónia policristalina tetragonal estabilizada com ítrio (3Y-TZP, ou Zircónia) com dimensões padrão (12 x 10 x 5 mm) foram preparados a partir de zircónia em estado verde (Lava Plus; 3M ESPE) com uma serra diamantada (Diamond wafering blade, N11-4244; 15HC) numa máquina de corte (Isomet 1000; Buehler). Os blocos foram polidos sob água corrente (DAP-U; Struers) com papel abrasivo de SiC (HV 30-800; Struers) de abrasividade decrescente (grão 220, 400 e 600) e lavados com água destilada durante 10 segundos com o intuito de remover os detritos. Após sinterizar de acordo com as instruções do fabricante (Lava Therm; 3M ESPE), uma superfície de cada bloco foi abrasionada com partículas em suspensão de óxido de alumínio (Al_2O_3) de 50 μm (Microetcher II; Danville Engineering) perpendicularmente à superfície do bloco (0,25 MPa pressão, 15 segundos, 10 mm distância). Os blocos de zircónia foram depois colocados em banho ultrassónico de etanol (Elmasonic One; Elma) durante 5 minutos. Cada bloco foi lavado com água durante 15 segundos e seco durante 15 segundos a uma distância de 10 mm.

Discos de resina composta (GrandioSO; Voco), cor A2, com dimensões padrão (5 x 2 mm) foram previamente fotopolimerizados durante 10 segundos com um aparelho de fotopolimerização (Ortholux LED Curing Light; 3M Unitek) com uma potência de 1200 mW/cm^2, confirmado com um radiómetro (Demetron LED Radiometer; Kerr Corp).

Os espécimes foram aleatoriamente divididos em 6 grupos experimentais (n=10) de acordo com as combinações possíveis entre o material de cimentação: 1) OptiBond XTR + NX3 Nexus; 2) Futurabond M+ + Bifix QM e a condição de contaminação: a) não contaminação; b) contaminação após a aplicação do sistema adesivo; c) contaminação antes da aplicação do sistema adesivo. Os espécimes contaminados foram expostos a saliva humana fresca, recolhida a partir de um doador saudável do género feminino, que não ingeriu qualquer alimento durante um período de 1,5 horas antes do processo de colheita. A saliva foi gentilmente espalhada sobre a superfície da zircónia com o auxílio de um *microbrush*, de acordo com a condição de contaminação: b) após a aplicação e fotopolimerização do adesivo mas antes da aplicação do cimento; ou c) diretamente na superfície da zircónia. Após um período de 10 minutos, durante o qual a saliva foi deixada em repouso, a superfície contaminada de cada bloco foi lavada com água durante 15 segundos e seca durante 15 segundos a uma distância de 10 mm.

Para os grupos OptiBond XTR + NX3 Nexus uma camada de adesivo OptiBond XTR foi aplicada durante 15 segundos e seca durante 5 segundos a uma distância de 10

mm, e fotopolimerizada durante 10 segundos. O cimento NX3 Nexus foi aplicado sobre a área de adesão, o disco de compósito foi colocado sore a superfície adesiva e o adesivo/cimento foi colocado sob pressão digital. O excesso de cimento foi removido e os espécimes foram fotopolimerizados, em duas faces opostas do disco durante 10 segundos cada.

Para os grupos Futurabond M+ + Bifix QM, o adesivo Futurabond M+ foi espalhado na área de adesão durante 20 segundos e seco durante 5 segundos a uma distância de 10 mm, e fotopolimerizado durante 10 segundos. O cimento foi aplicado sobre a área adesiva, o disco de compósito foi colocado sobre a superfície adesiva e o adesivo/cimento foi colocado sob pressão digital. O excesso de cimento foi removido e os espécimes foram fotopolimerizados, em duas faces opostas do disco durante 10 segundos cada.

Os espécimes foram colocados em água destilada a 37ºC e testados ao final de 48 horas. Os valores de força de adesão (SBS) foram medidos com um dispositivo de plano único numa máquina universal de ensaios (Instron model 4502, Instron Ltd) com 1 kN na célula de carga a uma velocidade de 0,5 mm/min. O modo de falha foi analisado usando um estereomicroscópio (EMZ-8TR, Meiji Techno Co) a uma ampliação de 20x. A falha foi classificada por 2 observadores independentes como adesiva, coesiva ou mista.

Os dados foram analisados estatisticamente com *software* adequado (IBM SPSS Statistics 20; SPSS Inc). Após inferir quanto à normalidade e homoscedasticidade com testes de Shapiro-Wilk e Levene ($p > 0,05$), os dados de SBS foram submetidos a uma análise *two-way* ANOVA com o intuito de explorar a influência da contaminação com saliva e o material de cimentação, seguido de testes Tukey-HSD *post-hoc* para múltiplas comparações entre grupos ($\alpha=0,05$). Testes de Kruskal-Wallis e Mann-Whitney foram usados para analisar os dados relativamente ao modo de falha ($\alpha=0,05$).

Resultados: Os valores de SBS variaram de 12,2 MPa para o grupo Futurabond M+ + Bifix QM quando os espécimes foram contaminados após a aplicação do sistema adesivo, e 22,0 MPa para os mesmos materiais de cimentação quando os espécimes não foram sujeitos a contaminação. A análise ANOVA e testes Tuckey-HSD *post-hoc* mostraram que a contaminação com saliva após a aplicação do sistema adesivo resultou em valores médios de SBS estatisticamente inferiores que os valores observados quando a contaminação ocorreu antes da aplicação do sistema adesivo ($p= 0,008$) ou quando os espécimes não foram sujeitos a contaminação ($p <0,001$). Não foram encontradas

diferenças entre os valores de adesão para os grupos de não contaminação e contaminação antes da aplicação do sistema adesivo (p= 0,297). Não foram encontradas diferenças estatisticamente significativas entre materiais de cimentação (p= 0,187), nem uma interação estatisticamente significativa entre os fatores (p= 0,007).

O modo de falha foi estatisticamente (p= 0,007) influenciado pela condição de contaminação. Os espécimes sujeitos a contaminação após a aplicação do sistema adesivo mostraram um padrão diferente de modo de falha, quando comparados com as condições de contaminação alternativas. Falhas coesivas foram apenas encontradas quando a contaminação com saliva foi efetuada após a aplicação do sistema adesivo. Não foram encontradas diferenças estatisticamente significativas (p= 1,000) entre os materiais de cimentação.

Conclusões: Dentro das limitações deste estudo, apesar de o material de cimentação utilizado não ter influenciado as forças de adesão à zircónia, a condição de contaminação teve influência. Lavar a zircónia contaminada com saliva com *spray* de água parece ser um método efetivo na sua descontaminação. No entanto, o sistema adesivo utilizado em combinação com o cimento deve ser aplicado antes do *try-in*.

Palavras-chave: Zircónia, Força de Cisalhamento, Contaminação com Saliva, Try-in, Adesão.

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I. Introduction

Over the last decades, major improvements relating to the mechanical properties of dental ceramics have been achieved (Wegner *et al*., 2002). Consequently, an increasing number of all-ceramic materials and systems are currently available for use (Kern *et al*., 2003). The introduction of zirconia as a dental material has generated considerable interest in the dental community, especially because of its excellent biocompatibility, improved mechanical strength and the high demand for metal-free and aesthetics restorations (Özkurt *et al*., 2008; Vigolo and Mutinelli, 2012; Presenda *et al*., 2015; Ioannidis and Bindl, 2016). These characteristics have given zirconia the potential to be applied as an alternative material to metal for the fabrication of frameworks. Due to the improvements in its aesthetic characteristics, such as its tooth-like optical properties, zirconia has been recently used even in monolithic restorations (Manicone *et al*., 2007).

Dental zirconia is, most often, a modified yttria tetragonal zirconia polycrystal (Y-TZP). Yttria is added to the ceramic with a view to stabilizing the crystal structure transformation during firing, improving the physical properties of zirconia (Della Bona *et al*., 2015). The zirconia tetragonal-to-monoclinic phase transformation is known to be a martensitic transformation (Della Bona, 2009; Della Bona *et al*., 2014). During this process, the unit cell of monoclinic configuration occupies about 4% more volume than the tetragonal one, which results in a relatively large volume change (Della Bona *et al*., 2015). This could result in the formation of ceramic cracks if no stabilizing oxides were used, such as yttria (Camposilvan *et al*., 2015). Hence, as the monoclinic phase does not form under normal cooling conditions, the cubic and tetragonal phases are retained, and crack formation, due to phase transformation, is avoided (Della Bona, 2009; Della Bona *et al*., 2015). In this case, the volume increase becomes beneficial for the material, essentially hindering crack propagation and increasing toughness, process known as transformation toughening (Della Bona *et al*., 2014; Camposilvan *et al*., 2015; Della Bona *et al*., 2015).

Due to its mechanical characteristics, in some situations, such as monolithic crowns, implant abutments or even endodontic posts, zirconia restorations do not require an adhesive cementation (Ha, 2015).

However, an acceptable resin bond may become necessary in various clinical situations, such as compromised retention and short abutment teeth (Kern *et al*., 2003;

Özkurt *et al*., 2008; Thompson *et al*., 2011; Ioannidis and Bindl, 2016; Shi *et al*., 2016). Consequently, most times, an adhesive technique is desirable since a strong, durable resin bond provides high retention, improves marginal adaptation and prevents microleakage, and increases fracture resistance of the restored tooth and the restoration. Adhesive bonding techniques and modern all-ceramic systems offer a wide range of highly aesthetic treatment options (Kern *et al*., 2003; Manicone *et al*., 2007; Thompson *et al*., 2011).

Bonding to traditional silica-based ceramics is a predictable procedure yielding durable results (Kamada *et al*., 2006; Kitayama *et* al., 2009; Thompson *et al*., 2011; Chen *et* al., 2013; Nakamura and Matsumura, 2014). However, the composition and physical properties of high-strength ceramic materials, such as zirconium oxide-based ceramics, differ substantially from the silica-based ceramics, which makes the acid conditioning with hydrofluoridric (HF) acid not effective, requiring alternative procedures to achieve micromechanical retentions and a strong, long-term, durable resin bond (Kern *et al*., 2003). Methods such as grinding, aluminium-oxide airborne particle abrasion, tribochemical silica coating, selective infiltration etching and laser-etching surface fluorination have been advocated for this purpose (Quaas *et al*., 2007; Thompson *et al*., 2011; Sato *et al*., 2015). Although there is no universally accepted surface treatment, aluminium-oxide sandblasting has been proven to increase surface roughness, area and energy, improving the adhesive strength achieved, and is commonly used to create micromechanical interlocking (Barragan *et al*., 2014; Angkasith *et al*., 2015; Ishii *et al*., 2015; Zhao *et al*., 2016).

Traditional adhesive procedures are, therefore, ineffective on zirconia surfaces, and the lack of silica makes it difficult to establish an adequate bond strength to methacrylate-based composite resins (Kern and Wegner, 1998). Some primers containing phosphate monomers, such as 10-methacryloyloxydecyl dihydrogen phosphate (MDP) have been used to promote adhesion between composite resin and zirconia, with promising results (Seabra *et al*., 2014). A phosphate monomer is a bifunctional monomer with a phosphate-based functional end that bonds to zirconia and a methacrylate-based functional end that bonds to resin cements. It has been proven that phosphate monomer-containing primer systems can, thus, effectively increase the bond strength to zirconia and the stability of these bonds to hydrolysis compared to older systems (Pott *et al*., 2015). Therefore, the adhesion between dental ceramics and resin-based composites is optimized when air-abraded surfaces are bonded with a phosphate monomer-containing composite

resin, resulting in high and durable bond strengths (Wolfart *et al*., 2007; Klosa *et al*., 2015).

A practical obstacle encountered while bonding to zirconia restorations is that salivary contamination during try-in of the restoration can weaken the bond to the resin cement (Zhang *et al*., 2010; Angkasith *et al*., 2015; Feitosa *et al*., 2015). It is to stress that saliva contamination is one of the most frequent reasons for failed bond strengths (Quaas *et al*., 2007). Saliva consists of organic materials such as salivary proteins, bacteria and food debris in water solution. After saliva contamination, salivary protein adsorption would occur not only on the tooth surface, but also on the restorative materials (Yang *et al*., 2008). Non-covalent adsorption of salivary proteins occurs on the surface after the contamination, which leads to the impossibility of achieving a durable bond to the ceramic after saliva contamination (Yang *et al*., 2008; Klosa *et al*., 2014). Salivary contamination of zirconia decreases the bond strength to zirconia (Yang *et al*., 2008; Zhang *et al*., 2010; Feitosa *et al*., 2015). Therefore, some cleaning techniques have been proposed, such as washing the bonding surface with organic solvents or alcohol, airborne particle abrasion or simply water rinsing (Zhang *et al*., 2010; Angkasith *et al*., 2015).

Water rinsing the bonding surface of zirconia is the easiest and most frequently used cleaning method by clinicians (Angkasith *et al*., 2015), reason why it was elected as the decontamination method in the present study. Decontamination results are not always satisfactory (Angkasith *et al*., 2015; Kim *et al*., 2015) for what it has already been suggested to perform the try-in procedure after the application of the adhesive. This is justified by the fact that this primer makes the zirconia surface slightly more hydrophobic, presumably, reducing salivary wetting ability and deposition of organic residue, thus protecting zirconia from saliva contamination (Angkasith *et al*., 2015). However, the effect of such procedure is not yet well documented.

II. Objectives

The aim of this research was to evaluate the ability to promote adhesion of two luting materials to saliva contaminated zirconia, according to the following null hypothesis:

1) The luting material does not influence bond strength to zirconia;

2) The timing of saliva contamination does not influence the bond strength to zirconia.

III. Materials and methods

1. Sample size calculation

In order to provide statistical significance (α=0.05) at 80% power, the sample size (n=10) was estimated with a power analysis, based on a pilot study.

2. Preparation of zirconia blocks

Sixty yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP, or zirconia) blocks with standard dimensions (12 x 10 x 5 mm) (Figure 1) were prepared from green-stage zirconia (Lava Plus; 3M ESPE) (Table 1) with a diamond saw (Diamond wafering blade, N11-4244; 15HC) in a cutting machine (Isomet 1000; Buehler). The blocks were polished under running water (DAP-U; Struers) with SiC abrasive paper (HV 30-800; Struers) of decreasing abrasiveness (220, 400, and 600 grit) and rinsed with distilled water for 10 seconds to remove debris. After sintering according to the manufacturer's instructions (Lava Therm; 3M ESPE), one surface of each block was abraded with 50 µm aluminum oxide (Al_2O_3) airborne particles (Microetcher II; Danville Engineering) perpendicular to the zirconia surface (0.25 MPa pressure, 15 seconds, 10 mm distance) (Figure 2). The zirconia blocks were then placed in an ethanol ultrasonic bath (Elmasonic One; Elma) for 5 minutes. Each block was rinsed with water for 15 seconds and air-dried for 15 seconds at 10 mm distance.

Figure 2: Zirconia block

Figure 1: Airborne particle abrasion

3. Preparation of composite disks

Disks of composite resin (GrandioSO; Voco), shade A2, with standard dimensions (5 x 2mm) (Figure 3) were previously light-cured for 10 seconds with a light curing device (Ortholux LED Curing Light; 3M Unitek) with an output of 1200 mW/cm^2, and checked with a radiometer (Demetron LED Radiometer; Kerr Corp).

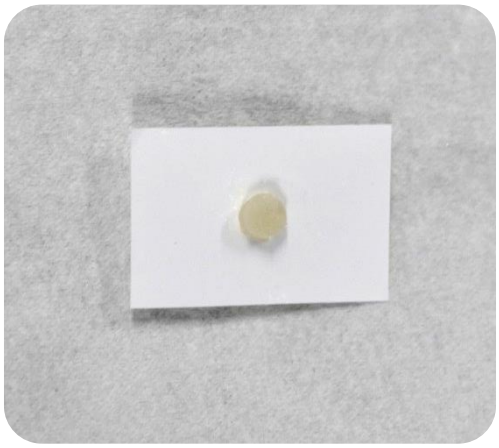

Figure 3: Composite disk

4. Application of the luting materials and contamination conditions

The specimens were randomly divided into 6 experimental groups (n = 10) according to the possible combinations between the luting materials: 1) OptiBond XTR + NX3 Nexus; 2) Futurabond M+ + Bifix QM) and the contamination condition: a) no saliva contamination; b) saliva contamination after the adhesive system application, c) saliva contamination prior to the adhesive system application (Figure 4).

Contaminated specimens were exposed to fresh human saliva, collected from a healthy female donor who had refrained herself from eating and drinking 1.5 hours prior to the collection process. The saliva was applied and gently rubbed over the bonding surface using a microbrush, according to the contamination condition, either: b) after the application and polymerization of the adhesive coat but before cement application; or c) directly onto the zirconia surface. After a period of 10 minutes, during which saliva was left undisturbed, the contaminated surface of each block was rinsed with water for 15 seconds and air-dried for 15 seconds at 10 mm distance.

For the OptiBond XTR + NX3 Nexus groups, a coat of OptiBond XTR adhesive was applied for 15 seconds and air-dried for 5 seconds at 10 mm distance, and light-cured for 10 seconds. The cement NX3 Nexus was applied over the bonding area, the composite disks were placed over the adhesive surface and the adhesive/cement was put under

constant manual pressure. Excess cement was removed and the specimens were light-cured, in 2 opposite margins of the disk for 10 seconds each.

For the Futurabond M+ + Bifix QM groups, the Futurabond M+ was rubbed onto the bonding area for 20 seconds and air-dried for 5 seconds at 10 mm distance, and light-cured for 10 seconds. The cement was applied over the bonding area, the composite disks were placed over the adhesive surface and the adhesive/cement was put under constant manual pressure. Excess cement was removed and the specimens were light-cured in 2 opposite margins of the disk for 10 seconds each.

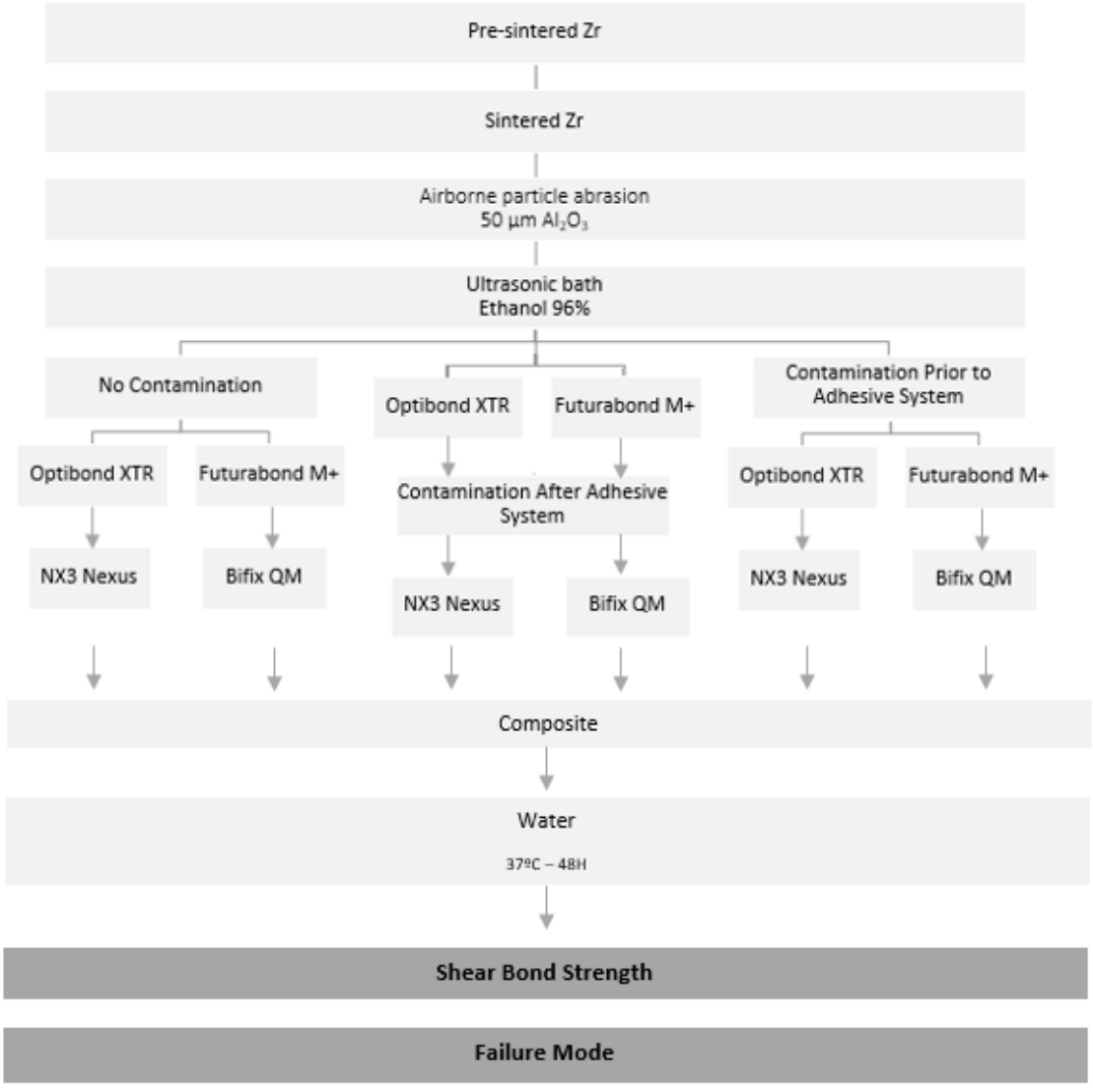

Figure 4: Experimental protocol

5. Storage procedure

Specimens were then stored in distilled water at 37ºC and tested after 48 hours.

6. Shear bond strength test (SBS) and failure mode analysis

SBS was measured with a single-plane lap device in a universal testing machine (Instron model 4502, Instron Ltd) (Figure 5) with a 1 kN load cell and at a crosshead speed of 0.5 mm/min. (Barragan *et al*., 2014). The failure mode was analysed with a stereomicroscope (EMZ-8TR, Meiji Techno Co) at 20x magnification (Figure 6). The failure was classified by 2 independent observers as adhesive if the failure occurred at the adhesive interface, as cohesive if the failure occurred within the composite resin, or as mixed if a combination of failures such as adhesive and cohesive was observed in the composite resin.

Figure 5: Shear Bond Strength (SBS) test

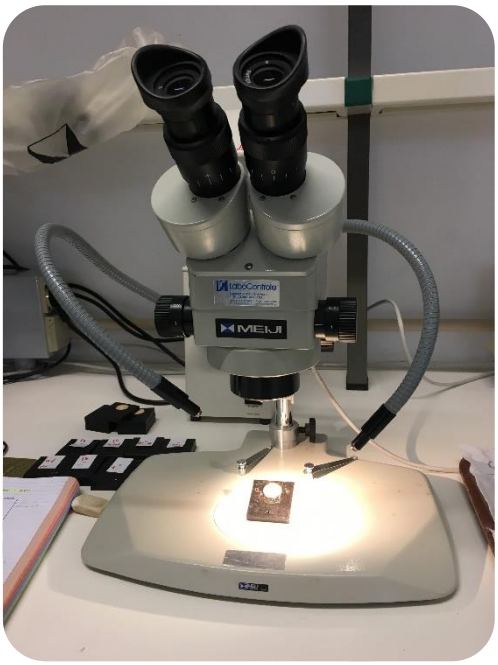

Figure 6: Failure mode analysis

Data were statistically analyzed with software (IBM SPSS Statistics 20; SPSS Inc). After assessing normality and homoscedasticity with Shapiro-Wilk and Levene tests ($p > 0.05$), SBS data were submitted to a 2-way ANOVA analysis to explore the influence of saliva contamination and luting materials, followed by Tukey-HSD post-hoc tests for multiple comparisons between groups ($\alpha = 0.05$). Kruskal-Wallis and Mann-Whitney tests were used to analyze the failure mode data ($\alpha = 0.05$).

Table 1: Materials employed and their characteristics

Material	Product Name	Manufacturer	Batch no.	Composition
Zirconia Ceramic	Lava Frame Zirconia	3M ESPE	476117	3Y-TZP
Universal Adhesive	OptiBond™ XTR	Kerr™	5812210 (12/2017)	**HEMA Adhesive:** Ethyl alcohol, alkyl dimethacrylate resins, barium aluminoborosilicate glass, fumed silica, sodium hexafluorosilicate
Universal Adhesive Resin Dental Cement	NX3 Nexus™	Kerr™	5671651 (04/2018)	Poly(oxy-1,2-ethanediyl), α,α'-[(1 methylethylidene)di-4,1-phenylene]bis[ω-[(2- methyl-1-oxo-2-propen-1-yl)oxy]-7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa- 5,12-diazahexadecane-1,16-diyl bismethacrylate, 2,2'-ethylenedioxydiethyl dimethacrylate, 2-hydroxyethyl methacrylate, 3-trimethoxysilylpropyl methacrylate, 1,1,3,3-tetramethylbutyl hydroperoxide
Universal Adhesive	Futurabond® M+	VOCO GmbH	1612531 (01/2018)	Bis-GMA, 2-hydroxyethyl methacrylate, HDDMA, Acidic Adhesive Monomer, urethanedimethacrylate, pyrogenic silicic acids, catalyst
Dual curing resin luting system	Bifix QM	VOCO GmbH	1615669 (04/2018)	HDDMA, Bis-GMA, catalyst, Benzoilperoxide Amines Baryum-aluminyum-borosilicate glass
Composite Resin	Grandio®SO	VOCO GmbH	1413449 (09/2016)	About 89% w/w **Filler** content: glass ceramic (average particle size of 1µm; functionalised silicon dioxide nano-particles (size of 20-40nm); **Pigments** (iron oxide, titanium dioxide). **Resin**: BisGMA, BisEMA, TegDMA. Camphorquinone as photocatalyst and butylated hydroxytoluene (BHT) as a stabilizer

*According to the information provided by the manufacturer

IV. Results

The mean SBS ranged between 12.2 MPa for the Futurabond M+ + Bifix QM when the specimens were contaminated after the application of the adhesive system, and 22.0 MPa for the same luting materials when the specimens were not contaminated (Table 2)

Table 2: Descriptive statistics of shear bond strength (SBS) and failure mode (n=10).

Contamination Condition	Luting Materials	SBS (MPa)		Failure Mode [n (%)]		
		Mean	SD	Adhesive	Mixed	Cohesive
No Contamination	OptiBond XTR / Nexus NX3	20.0	4.95	5 (50%)	5 (50%)	0 (0%)
	Futurabond M+ / Bifix QM	22.0	5.70	5 (50%)	5 (50%)	0 (0%)
Contamination After Adhesive System	OptiBond XTR / Nexus NX3	13.8	3.70	1 (10%)	6 (60%)	3 (30%)
	Futurabond M+ / Bifix QM	12.2	5.07	3 (30%)	4 (40%)	3 (30%)
Contamination Prior to Adhesive System	OptiBond XTR / Nexus NX3	21.5	6.69	6 (60%)	4 (40%)	0 (0%)
	Futurabond M+ / Bifix QM	15.3	6.29	4 (40%)	6 (60%)	0 (0%)

ANOVA (Table 3) and Tukey-HSD post-hoc tests showed that saliva contamination after the adhesive system application resulted in statistically lower SBS mean values than the adhesive strength observed when saliva contamination was performed prior to adhesive application ($p = 0.008$) or when the specimens were not contaminated ($p < 0.001$) (Figure 7). No differences were found between SBS for no contamination and saliva contamination prior to adhesive application groups ($p = 0.297$).

Table 3: Two-way ANOVA

Source	Sum of Squares	df	Mean Square	F	Sig.
Contamination Condition	672.688	2	336.344	11.169	0.000
Luting Materials	53.884	1	53.884	1.789	0.187
Contamination Condition * Luting Materials	168.617	2	84.309	2.800	0.070
Error	1626.177	54	30.114		
Total	2521.367	60			

Neither statistically significant differences between luting materials (p = 0.187) (Figure 8) nor a statistically significant interaction between factors (p = 0.070) were identified.

Failure mode was statistically (p = 0.007) influenced by contamination conditions (Figure 9). Specimens made with saliva contamination after adhesive system application showed a different pattern when compared to the other two saliva contamination procedures. Cohesive failures were only found when saliva contamination was performed after adhesive system application. No statistically significant (p = 1.000) difference was found between luting materials (Figure 10).

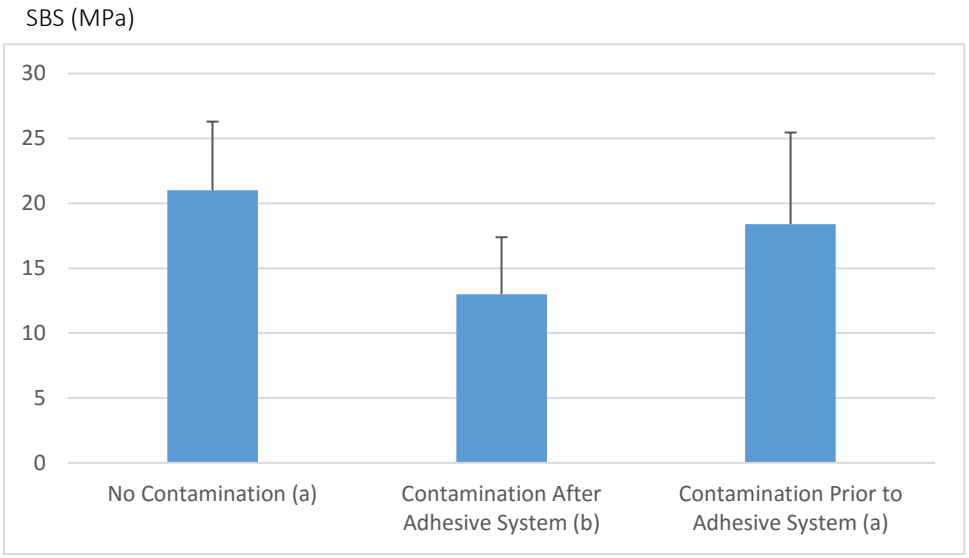

Figure 7: Influence of contamination condition on shear bond strength between zirconia and composite resin. Means with similar superscript letters were not statistically different (p > 0.05).

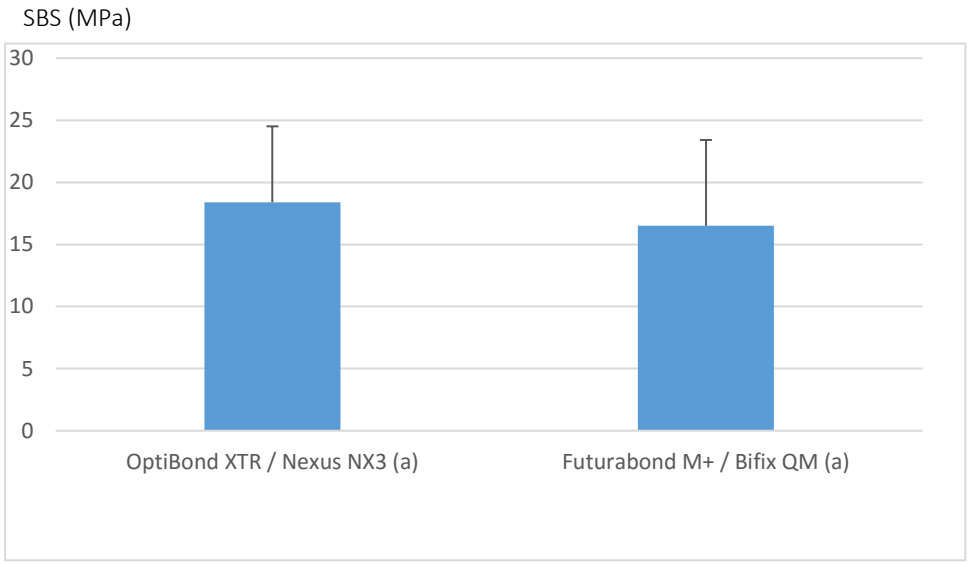

Figure 8: Influence of luting materials on shear bond strength between zirconia and composite resin. Means with similar superscript letters were not statistically different (p > 0.05).

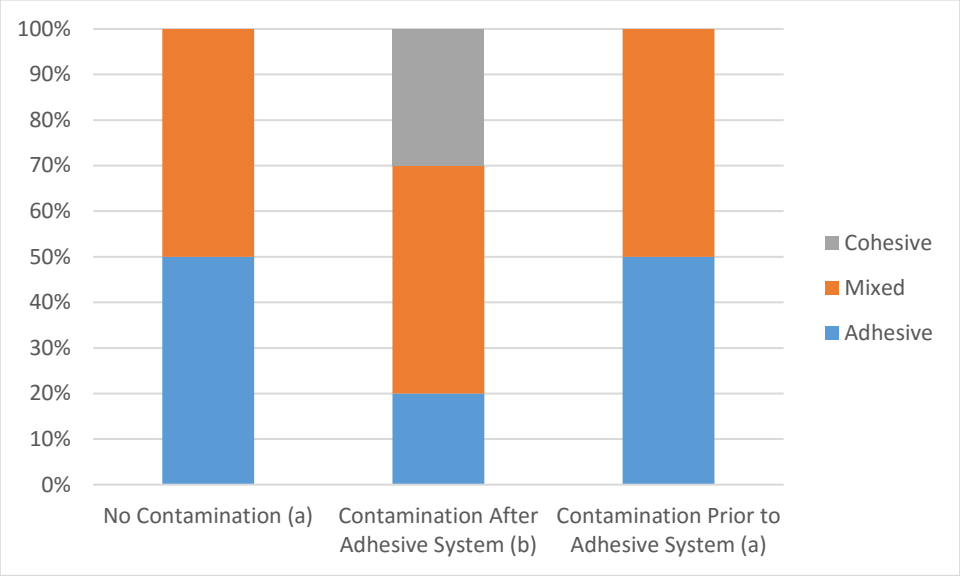

Figure 9: Type of bonding failure mode as identified with a stereomicroscope at 20x magnification and calculated in percentage of the bonding area for all contamination procedures, after shear bond strength testing. ***Adhesive failure:*** *debonded failure at the zirconia surface (Figure 11).* ***Mixed failure:*** *debonded failure with composite resin (Figure 12).* ***Cohesive failure:*** *debonded failure within adhesive/composite resin (Figure 13). There is a statistically significant difference between the failure mode and the saliva contamination procedure (p = 0.007).*
Means with similar superscript letters were not statistically different (p > 0.05).

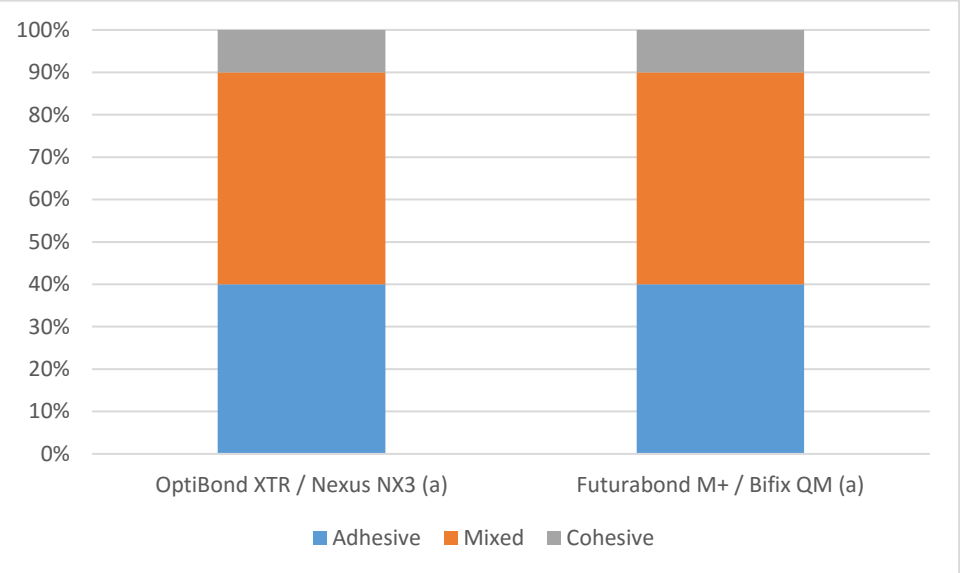

Figure 10: Type of bonding failure mode as identified with a stereomicroscope at 20x magnification and calculated in percentage of the bonding area for all adhesive systems, after shear bond strength testing. ***Adhesive failure:*** *debonded failure at the zirconia surface (Figure 11).* ***Mixed failure:*** *debonded failure with composite resin (Figure 12).* ***Cohesive failure:*** *debonded failure within adhesive/composite resin (Figure 13). There was no statistically significant difference between the adhesive systems and the failure mode (p = 1.000).*
Means with similar superscript letters were not statistically different (p > 0.05).

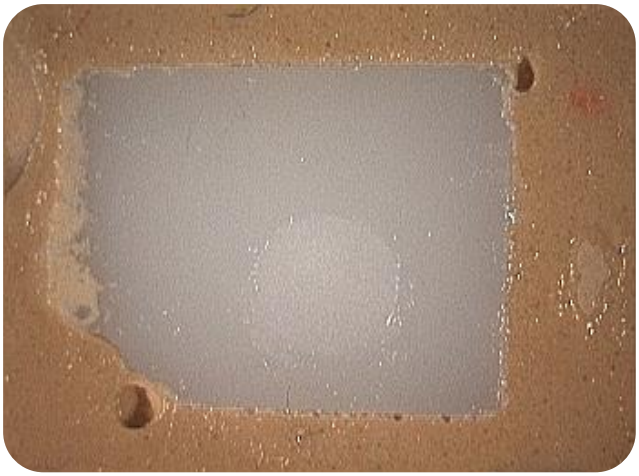

Figure 11: Adhesive failure mode

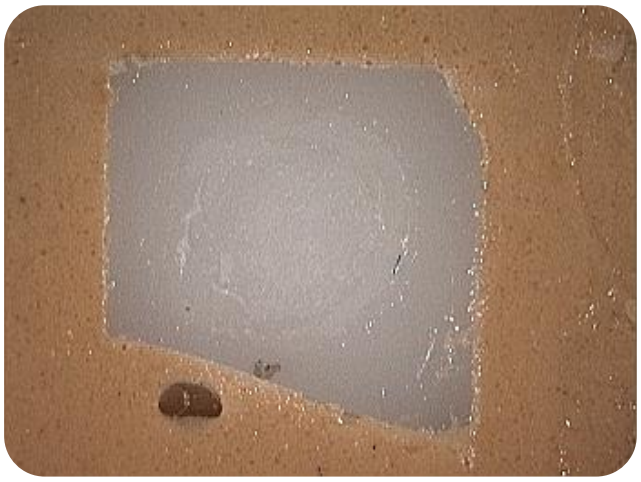

Figure 12: Mixed failure mode with composite

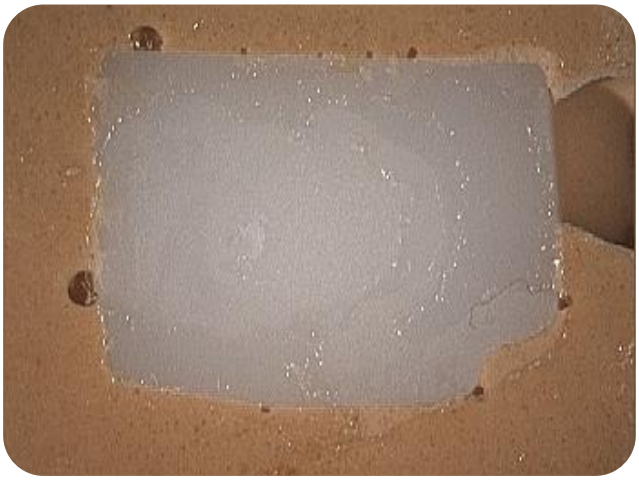

Figure 13: Cohesive failure mode within adhesive/resin

V. Discussion

As proven in previous studies, micromechanical conditioning of zirconia surface improves adhesive strength (Kern and Wegner 1998; Cavalcanti *et al*., 2009; Barragan *et al*., 2014). Air-abrading the surface increases the surface area as well as its surface energy, which will affect the wettability, allowing the cement to flow into the retentions previously created. A stronger micromechanical lock is, thus, created.

Despite concerns that the impact of aluminum oxide particles on the ceramic surface may generate fracture lines that lead to a decrease in cohesive strength, some researchers report that a transformation from tetragonal to monoclinic phase on yttria stabilized tetragonal zirconia polycrystals due to sandblasting counteracts the effect of these flaws on the material strength (Thompson *et al*., 2011; Barragan *et al*., 2014). Nevertheless, it seems to be a trend to use a reduced particle size and low airborne abrasion pressure as the treatment of choice for acid-resistant ceramics (Della Bona *et al*., 2014). In previous studies, the mechanical conditioning of the zirconia surface has been proven efficient in creating microretentions and improving adhesion (Kern and Wegner, 1998). Increasing zirconia roughness not only led to a higher surface area for micromechanical retention, but also increased the surface energy and therefore wettability and adhesion. Zirconia airborne particle abrasion with 50 µm Al_2O_3 under a pressure of 0.25 MPa has proven to be effective for that purpose (Seabra *et al*., 2014). As so, in the present study all specimens were submitted to this micromechanical condition method.

Nonetheless, and despite its essential role in achieving clinically acceptable bonds, microretention has not yet been proven to be sufficient in doing so on its own (Inokoshi *et al*., 2013). The introduction of an additional chemical treatments is, therefore, needed in order to establish a chemical union to zirconia (Seabra *et al*., 2014). Primers containing phosphate monomers, such as 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), or other acidic monomers are often used (Yang *et al*., 2008; Angkasith *et al*., 2015, Della Bona *et al*., 2015). The functional phosphate ester group of these monomers seems to form a water-resistant chemical bond with zirconia (Thompson *et al*., 2011).

In the present study, no statistically significant differences were found between the luting materials, thus, the first null hypothesis cannot be rejected. An explanation for this fact might be the similarity between the materials employed, and because both

adhesives present phosphate monomers capable of adhering to zirconia. Similarly to SBS values, the bonding failure mode showed no statistically significant differences between adhesive systems, as previously stated (Zhao *et al*., 2016). A previous study has reported that adhesives similar in composition lead to similar SBS values, as well as patterned failure modes (Lagodzinska *et al*., 2014).

A clinical obstacle often encountered while bonding to an oxide ceramic restoration is the saliva contamination that occurs during try-in procedures, which can weaken the bond to the resin cement. The process consists of a non-covalent adsorption of salivary proteins on the bonding surface, which may adversely affect resin bonding (Yang *et al*., 2008; Angkasith *et al*., 2015).

According to previous studies, saliva contamination should be harmful to zirconia bonding (Quaas *et al*., 2007; Yang *et al*., 2008; Zhang *et al*., 2010; Klosa *et al*., 2014; Angkasith *et al*., 2015). Various procedures have been proven efficient on decontaminating the bonding surface of zirconia, such as water, alcohol, phosphoric acid and additional airborne particle abrasion (Feitosa *et al*., 2015). It has been stated that water rinsing is a valid decontamination protocol, able to restore the original bond strength values (Angkasith *et al*., 2015), reason why the water rinsing was the chosen method for decontamination.

In an attempt to avoid the adhesion of saliva phosphates to the surface of zirconia, it has been suggested that the application of a phosphate monomer-containing adhesive system to the bonding surface made the zirconia slightly more hydrophobic, presumably, reducing salivary wetting ability and deposition of organic residues, which would result in the protection of the surface from saliva contamination (Chen *et al*., 2013; Angkasith *et al*., 2016). For this reason, it makes sense to evaluate the application of the adhesive system prior to saliva contamination, as shown in this research. However, in the present study, this was not verified, showing statistically significant inferior results precisely the groups subjected to saliva contamination after the application of the adhesive system.

In fact, in the present study, the timing of contamination influenced the SBS values, whereby the second null hypothesis has to be rejected. The groups where no contamination was performed and performed prior to the adhesive system showed statistically similar results, which seems to show that either the decontamination protocol with water, or the acidic monomers present in the adhesive systems allowed to break the links between saliva and zirconia. Therefore, the adhesive system should be applied after

decontamination of the bonding surface, regardless of its previous application, in order to optimize the bonding resistance. These results are in accordance with previous studies, which state that removing saliva contamination before the application of the adhesive system enhances the resin bond strength (Ishii *et al*., 2015; Kim *et al*., 2015).

Differences between failure modes were not in accordance with the results in the SBS analysis. There are both adhesive (Figure 11) and mixed (Figure 12) failure modes when it comes to no contamination and contamination prior to the adhesive system groups. On the other hand, there is a decrease in the adhesive failure mode, and the appearance of a cohesive (Figure 13) failure mode concerning the group contaminated after the application of the adhesive system. This might be justified by the persistence of saliva remnants on the adhesive surface, which results in the failure of the bond established between the adhesive and the cement, and therefore a decrease in the strength bond. These results are not in accordance with previous studies, which state that an adhesive failure mode is associated with lower SBS values, whereas cohesive and mixed failure modes are linked to higher bond strengths (Valandro *et al*., 2008; Attia *et al*., 2011; Seabra *et al*., 2014). One can assume that applying the adhesive system before the try-in procedure will decrease the future bond between the adhesive coat and the luting cement.

According to recent studies, the most commonly applied test method for assessing bonding efficacy to zirconia is a shear bond strength test (Papia *et al*., 2013; Inokoshi *et al*., 2014). The advantage of the SBS test is that it is easy to use, and there is no need for further preparation of the specimens prior to test (Zhao *et al*., 2016).

One limitation of the present study was the lack of thermal cycling of the sample. Even though high initial bond strength values for all bonded specimens are expected, because an adhesive from a chemical aspect initially attaches well to contaminated surfaces and because an immediate elimination of the contaminants from the bonding surface is usually performed, it is however expected the occurrence of a deterioration of the bond, which may certainly compromise the bonding in the short run (Aladag *et al*., 2014). Thermal cycling is expected to lead to a degradation of the interface, probably caused by hydrolysis of the chemical bond formed and the stress induced by the process, which artificially mimics the intra-oral aging process (Wegner *et al*., 2002). Thermal cycling should, therefore, be performed to infer as to long-term bonding resistance, so as to allow drawing conclusions for long-term stability of the bond in the mouth. Another

limitation is that only salivary contamination was considered. However, blood, stone and silicone try-in pastes are also possible contaminants (Angkasith *et al*., 2016).

Furthermore, the fact that the present research represents an in vitro study, in addition to the fact that the sample used was rather small, prevents the extrapolation of the data to a clinical environment. Further studies, as well as long-term clinical results should be obtained for a valid recommendation of the try-in protocol, as well as the adhesive strategy when it comes to bonding to an oxide ceramic, such as zirconia.

VI. Conclusions

Within the limitations of the present study, despite the fact that the luting material used did not influence bond strength to zirconia, the timing of saliva contamination did. To rinse saliva contaminated zirconia surfaces seems to be an effective method for saliva decontamination. However, the adhesive system used combined with cements should be applied before try-in.

VII. Appendices

A. APPENDIX A – Data Base

Table 4: Data base

N	Group	Contamination Condition	Luting Material	Force (N)	MPa	Failure Mode
1	1	3	1	173,7	24,57	1
2	1	3	1	182,5	25,82	1
3	1	3	1	158,5	22,42	1
4	1	3	1	146	20,65	2
5	1	3	1	93,6	13,24	2
6	1	3	1	187,5	26,53	1
7	1	3	1	141,2	19,98	1
8	1	3	1	160,5	22,71	1
9	1	3	1	219,4	31,04	2
10	1	3	1	55,8	7,9	2
1	2	3	2	120,3	17,02	1
2	2	3	2	158,7	22,45	1
3	2	3	2	81,4	11,52	2
4	2	3	2	40,4	5,72	2
5	2	3	2	190	26,88	1
6	2	3	2	89,7	12,69	2
7	2	3	2	130,8	18,5	2
8	2	3	2	95,4	13,5	2
9	2	3	2	114,3	16,17	1
10	2	3	2	63,1	8,93	2
1	3	2	1	140,8	19,92	1
2	3	2	1	81,2	11,49	2
3	3	2	1	113,2	16,01	2
4	3	2	1	110,8	15,67	3
5	3	2	1	69,6	9,84	2
6	3	2	1	73,1	10,34	2
7	3	2	1	95,1	13,45	3
8	3	2	1	84,4	11,94	3
9	3	2	1	71,4	10,11	2
10	3	2	1	134,3	19	2
1	4	2	2	77,3	10,94	2

2	4	2	2	107,9	15,26	2
3	4	2	2	39,7	5,62	2
4	4	2	2	111,8	15,82	1
5	4	2	2	114,2	16,16	1
6	4	2	2	46	6,51	3
7	4	2	2	154	21,79	1
8	4	2	2	54,1	7,65	3
9	4	2	2	75,1	10,63	2
10	4	2	2	81,6	11,54	3
1	5	1	1	154,9	21,91	1
2	5	1	1	172,4	24,39	1
3	5	1	1	139,3	19,71	1
4	5	1	1	46,6	6,59	2
5	5	1	1	150	21,22	1
6	5	1	1	140,4	19,86	2
7	5	1	1	141,9	20,07	2
8	5	1	1	159,6	22,58	2
9	5	1	1	163,1	23,07	2
10	5	1	1	145,6	20,6	1
1	6	1	2	121,7	17,22	2
2	6	1	2	230,8	32,65	1
3	6	1	2	157,8	22,32	2
4	6	1	2	158,9	22,48	2
5	6	1	2	175	24,76	1
6	6	1	2	181,6	25,69	1
7	6	1	2	103,7	14,67	1
8	6	1	2	188,7	26,7	1
9	6	1	2	105,3	14,9	2
10	6	1	2	134,9	19,08	2

Table 5: Groups data base

Group	Description
1	Contamination Prior to Adhesive System + Optibond XTR / Nexus NX3
2	Contamination Prior to Adhesive System + Futurabond M+ / Bifix QM
3	Contamination After Adhesive System + Optibond XTR / Nexus NX3
4	Contamination After Adhesive System + Futurabond M+ / Bifix QM
5	No Contamination + Optibond XTR / Nexus NX3
6	No Contamination + Futurabond M+ / Bifix QM

Table 6: Contamination conditions data base

	Contamination Condition
1	No Contamination
2	Contamination After Adhesive System
3	Contamination Prior to Adhesive System

Table 7: Luting material data base

	Luting Material
1	OptiBond XTR / Nexus NX3
2	Futurabond M+ / Bifix QM

Table 8: Failure mode data base

	Failure Mode
1	Adhesive
2	Mixed with Composite
3	Cohesive within Adhesive/Resin

B. APPENDIX B – Manufacturer's Instructions Kerr

OptiBond XTR

Metal-based, Zirconia-based, Alumina-based, and Composite Restorations:

Sandblast the internal surface with 50µ alumina with a pressure of about 60 psi (0.4 MPa) for metal-based, zirconia-based and alumina-based restorations, or a pressure of about 15 psi (0.1 MPa) for composite restorations. Apply a coat of OptiBond XTR ADHESIVE on the internal surface of the restoration, air thin with gentle air first and then strong air to avoid pooling of OptiBond XTR ADHESIVE, and light-cure for 10 seconds.

*(Light-curing of OptiBond XTR ADHESIVE is optional if NX3 resin cement is used for cementation).

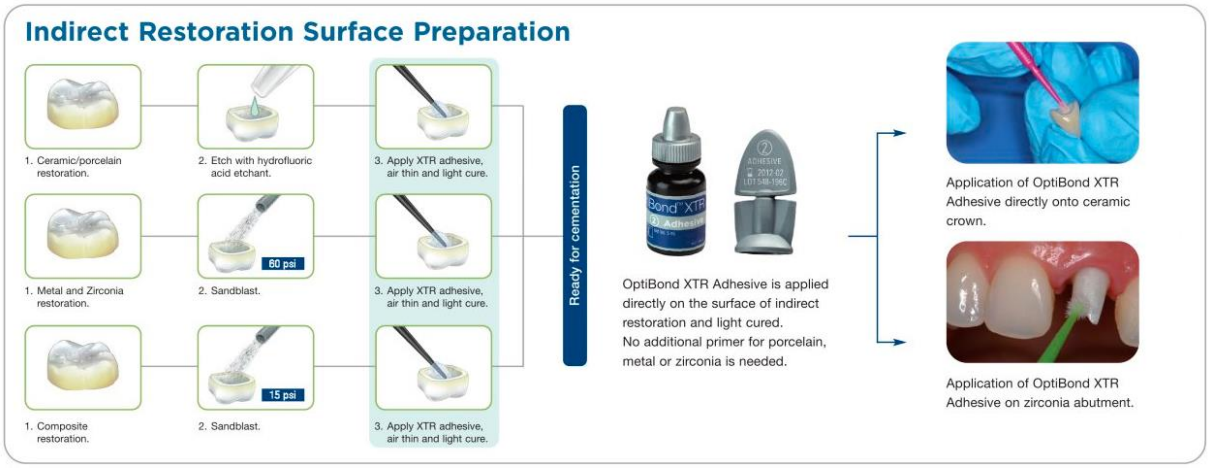

Figure 14: Instructions for use – OptiBond XTR (Kerr)

NX3 Nexus

Crowns, bridges, inlays, onlays, and metal-based restorations:

Note: On the prep, avoid pooling of adhesive before light curing of adhesive.

Excess adhesive can be removed with a dry applicator brush before light-curing of the adhesive. Apply the dual-cure cement to the restoration or the prep. Seat the restoration gently onto the preparation allowing the cement to flow from all sides.

Remove excess cement. Light cure all surfaces for a minimum of 10 s per surface.

Excess cement clean-up – Excess cement is best removed in its gel state with a scaler or explorer. Gel state can be achieved by tack curing excess with a light for 1-2 seconds or allowing the cement to self-cure for 2-3 minutes after application.

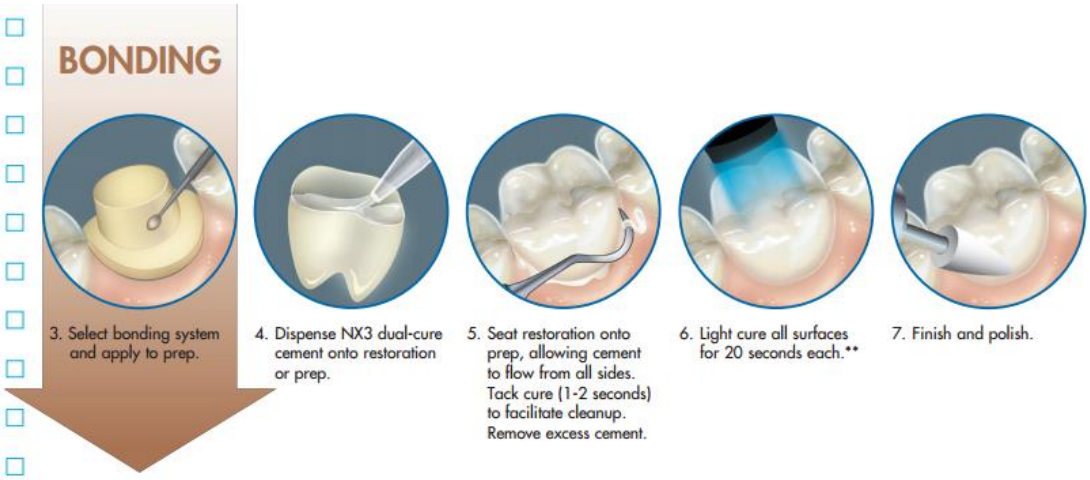

Figure 15: Instructions for use – NX3 Nexus (Kerr)

C. APPENDIX C – Manufacturer's Instructions VOCO GmbH

Futurabond M+

Metal-based, Zirconia-based, Alumina-based, and Composite Restorations:

Place one drop of Futurabond M+ on a mixing palette. Apply the adhesive evenly to the surfaces of the cavity and rub it in for 20 s with a disposable applicator. Dry off the adhesive layer with dry, oil-free air for at least 5 s in order to remove any solvents. Cure the adhesive layer for 10 s using a commercially available polymerisation device (LED or halogen light with an output of > 500 mW/ cm²).

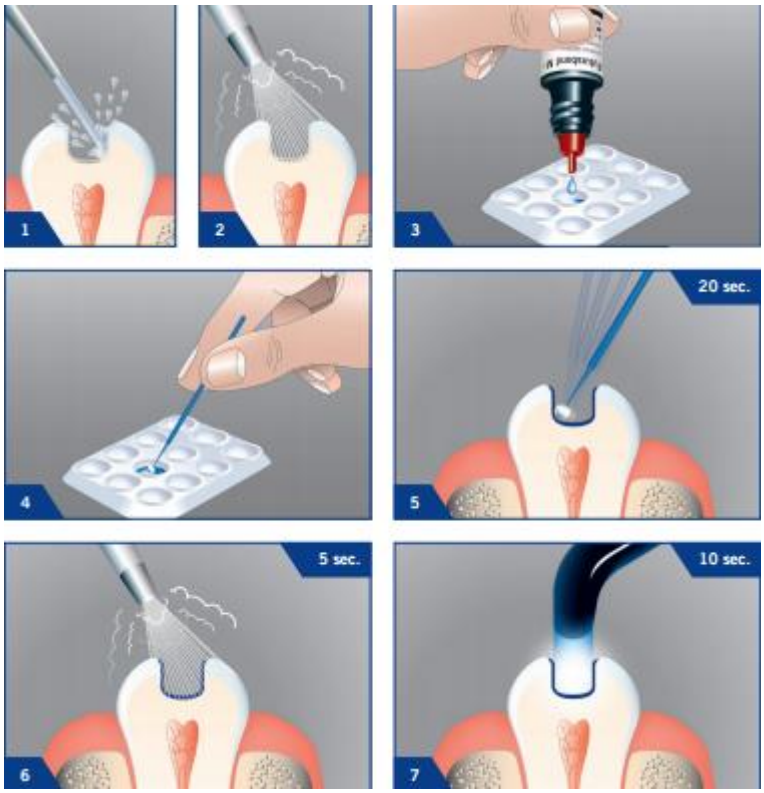

Figure 16: Instructions for use – Futurabond M+ (VOCO)

Bifix QM

Apply the dual-cure cement to the restoration or the prep. Seat the restoration gently onto the preparation allowing the cement to flow from all sides. Remove excess cement. Light cure all surfaces for a minimum of 10 s per surface.

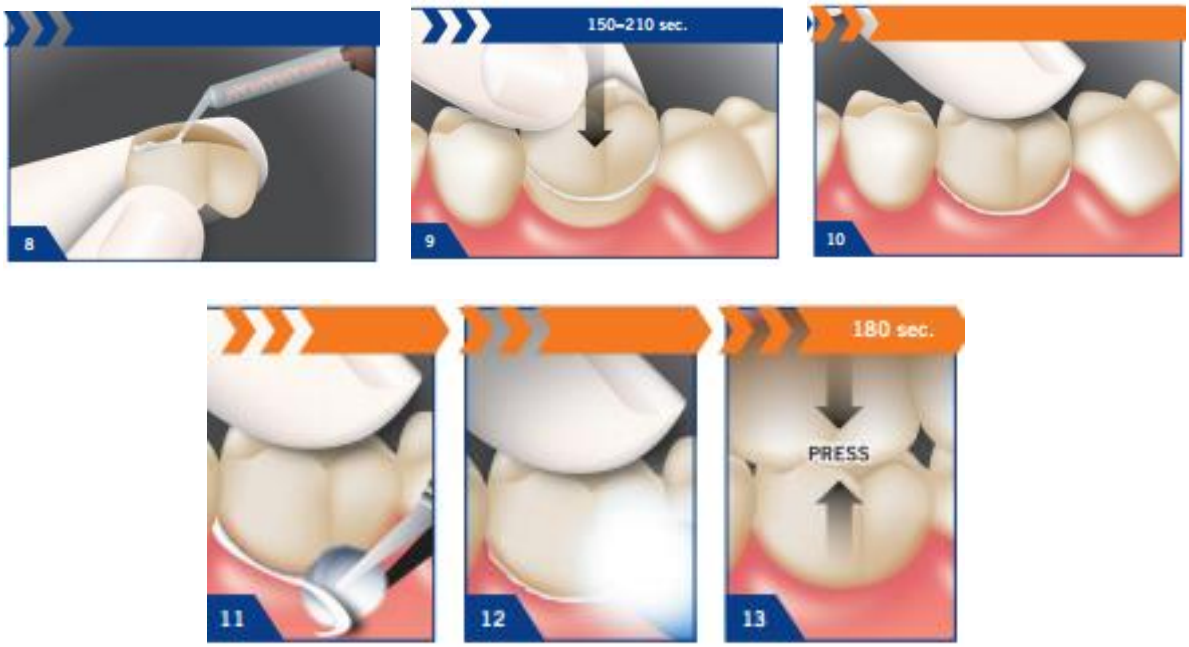

Figure 17: Instructions for use – Bifix QM (VOCO)

GrandioSo – Resin Composite

Application of GrandioSO: Apply the selected shade of GrandioSO (see shade selection) in layers that are a maximum of 2 mm thick, adapt with a suitable instrument and light-cure afterwards. Light-curing: Conventional polymerisation devices are suitable for light-curing the material.

The curing time is as follows when using an LED-/ halogen light with a minimum light-output of 500 mW / cm² 20 s for shades A1, A2, A3, A3.5, A4, B1, B2, B3, C2, D3, BL, GA3.25 40 s for shades OA1, OA2, OA3.5, GA5 The curing time is as follows when using an LED-/ halogen light with a minimum light-output of 800 mW / cm² 10 s for shades A1, A2, A3, B1, BL 20 s for shades A3.5, A4, B2, B3, C2, D3, GA3.25, GA5 40 s for shades OA1, OA2, OA3.5 Hold the light emission tip of the device as close as possible to the surface of the filling. Otherwise, the curing depth may be reduced. Incomplete curing may lead to discolouration and discomfort.

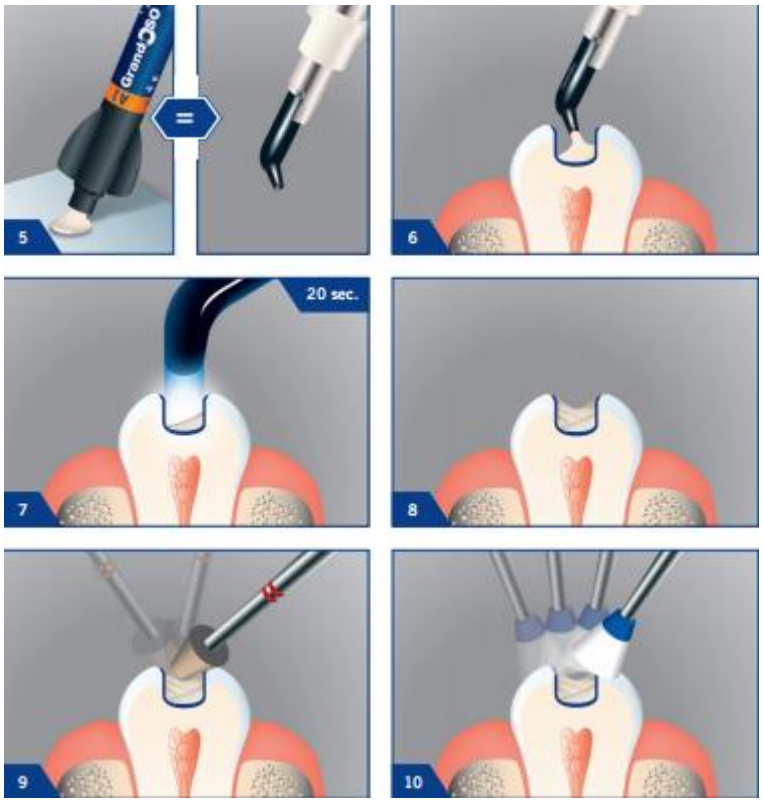

Figure 18: Instructions for use – GrandioSo (VOCO)

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