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A Scoping Review on Wear Pathways of Current Occlusal Fissure Sealants

Andreia Vanessa da Silva Guedes

Dissertação conducente ao Grau de Mestre em

Medicina Dentária (Ciclo Integrado)

Gandra, 5 de Junho de 2020

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Trabalho realizado sob a Orientação de Professora Margarida Faria e Professor Júlio Souza

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Eu, **Ana Margarida de Freitas Peixoto de Guedes Faria**, com a categoria profissional de **Assistente Convidada do Instituto Universitário de Ciências da Saúde**, tendo assumido o papel de Orientadora da Dissertação intitulada "*A Scoping of Review on Wear Pathways of Current Occlusal Fissure Sealants*" da aluna do Mestrado Integrado em Medicina Dentária, **Andreia Vanessa da Silva Guedes**, declaro que sou de parecer favorável para que a Dissertação possa ser depositada para análise do Arguente do Júri nomeado para o efeito para Admissão a provas públicas conducentes à obtenção do Grau de Mestre.

Gandra, 5 de Junho de 2020

A orientadora

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RESUMO

O selamento de fossas e fissuras oclusais de molares e pré-molares é considerado uma terapia eficaz para a prevenção da cárie dentária. Os selantes têm resistência limitada ao desgaste, resultando em danos na superfície e perda de volume do selante. O objetivo deste estudo é realizar uma revisão sistemática integrativa da literatura sobre as vias de desgaste dos selantes de fissuras oclusais atuais.

Uma revisão sistemática integrativa da literatura foi elaborada com base na pesquisa na base de dados (Medline / PubMed), usando as seguintes combinações de palavras-chave: occlusal fissure sealant OR fissure sealant OR pit sealant AND degradation OR wear OR erosion OR aging.Os critérios de inclusão envolveram artigos publicados no idioma em inglês nos últimos 20 anos sobre os mecanismos de degradação predominantes em fissuras oclusais de selantes. Na estratégia de pesquisa foi feita uma triagem e seleção dos artigos por título e resumo e, em seguida, pela leitura completa dos artigos mais relevantes. A hipótese colocada foi de que os selantes de matriz de resina têm uma resistência ao desgaste variável, considerando a composição química orgânica e o conteúdo das partículas de carga, e os selantes de ionómero de vidro sofrem um maior desgaste da superfície quando, comparados aos selantes de matriz de resina.

PALAVRAS-CHAVE

Selantes de fissura; Degradação; Erosão; Desgaste; Envelhecimento.

ABSTRACT

Sealing the occlusal pits and fissures of molars and premolars is considered an effective therapy for the prevention of dental caries. Such sealants have limited wear resistance, resulting in surface damage and sealant volume loss. The purpose of this study is to perform a scoping review of the literature on wear pathways of current occlusal fissure sealants.

A scoping review of the literature was performed based on database search (Medline/PubMed) using the following combinations of key terms: occlusal fissure sealant OR fissure sealant OR pit sealant AND degradation OR wear OR erosion OR aging. The inclusion criteria involve articles published in the English language within the last 20 years on the dominant degradation mechanisms of occlusal sealant fissures. The search strategy deals with the preliminary screening and selection of the articles by title and abstracts and then the full-reading of the most relevant articles. It was hypothesized that resin-matrix sealants have a variable wear resistance considering the organic chemical composition and content of fillers, and the glass-ionomer sealants have a higher surface wear damage when compared to resin-matrix sealants.

KEYWORDS

Fissure sealants; Degradation; Erosion; Wear; Aging.

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TABLE OF CONTENTS

1. INTRODUCTION

Sealants act as a protective barrier in the pits and fissures of occlusal surfaces of teeth and preventing dental caries. Sealants are classified into three types: resins, glass-ionomers, and polyacid modified resins (1). There is no evidence on which type of material is the most effective (2). Nowadays, two predominant types of occlusal sealants used in practice are composed of resin-matrix composite and glass-ionomers (3). Low wear resistance and strength of sealants remain a significant clinical problem, resulting in fracture and increased roughness. That last problem results in biofilm accumulation, leading to high susceptibility to caries process (4). The chemical composition of occlusal fissure sealants has been changing, and materials with high strength, wear resistance, and adhesion to enamel are nowadays used in the preparations. The viscosity of sealants is crucial to penetrate throughout the occlusal pits and fissures (5). Size, shape, and content of fillers can affect the mechanical properties and flow of the sealant, once the filler content and size are inversely proportional to the flow (1). Resin-matrix sealants (RMS) have a combination of monomers, used to control its viscosity and mechanical properties. In the case of glass-ionomer (GI) sealants, the chemical adhesion between carboxylic groups and enamel is the most advantageous characteristic, once the clinical procedures avoid the damage of enamel (6). The conventional GI modified by the addition of light-cured resin monomers (hydroxyethyl methacrylate - HEMA) is classified as a resin-modified glass-ionomer (RMGI). The modification of glass ionomer adding resins improves its mechanical and optical properties (7).

In the oral cavity, wear of dental restoratives occurs when opposing teeth become in contact and cause loading during mastication or other parafunctional activities (6). *In vitro* wear can be determined by pin-on-disc or ball-on-flat methods and by human oral simulator devices (8). The wear pathways are affected by several factors, namely the shape and hardness of the particles, the quality of the bond between particles and matrix, the polymerization degree, the elastic modulus, the mechanical strength, the hardness of the counter-body and the environmental conditions that may increase the wear (9). Nevertheless, over time the degradation of fissure sealants commonly occurs due to mechanical solicitations and by the presence of acidic substances such as citric acid, lactic

acid, and acid beverages in general (10). Materials has been improved by including a high content of particles at micro and nano-scale to increase the hardness and strength viewing to minimize the sealant wear (6).

It is essential to know the sealant wear resistance, and consequently its duration, to schedule recall appointments which will check the status of the restorations and avoid failures (11). This study aimed to develop a scoping review on wear pathways of current occlusal fissure sealants.

The hypothesis formulated was: RMS have a variable wear resistance considering their organic chemical composition and the content of fillers, and the GI sealants have a higher surface wear damage when compared to resin-matrix sealants.

2. METHOD

A literature search was carried out on PUBMED/Medline (via National Library of Medicine) using the following key term combinations: "occlusal fissure sealant" OR "pit sealant" OR "fissure sealant" AND "degradation" OR "wear" OR "erosion" OR "aging". Inclusion criteria were as follows: articles written in English, published between January 1999 and December 2019, studies on the dominant degradation mechanisms of sealant occlusal fissure, including randomized controlled trials, *in vitro* and *in vivo* studies . Two authors (AVSG, AMFPGF) independently evaluated the titles and abstracts of the most relevant articles. The total of articles was compiled for each combination of key terms, and the duplicates were removed using Mendeley citation manager. A preliminary evaluation of the abstracts was carried out to establish whether the articles met the purpose of the study. The selected articles were read individually, considering the objective of the study. The following variables were recorded for this study: authors' names, journal title, publication year, purpose, materials tested, wear challenge method and wear assessment, namely wear rate, wear volume, microleakage and main outcomes.

3. RESULTS

The literature search on PubMed identified a total of 228 articles, although 18 were duplicate and were then removed (Fig. 1). After reading and analyzing the titles and

abstracts of the identified studies, 185 articles were excluded because they did not meet the inclusion criteria. The remnant 25 studies were then selected for full-reading. Four articles were then excluded due to the lack of relevant information for the present study. Finally, 21 studies were included in this scoping review.

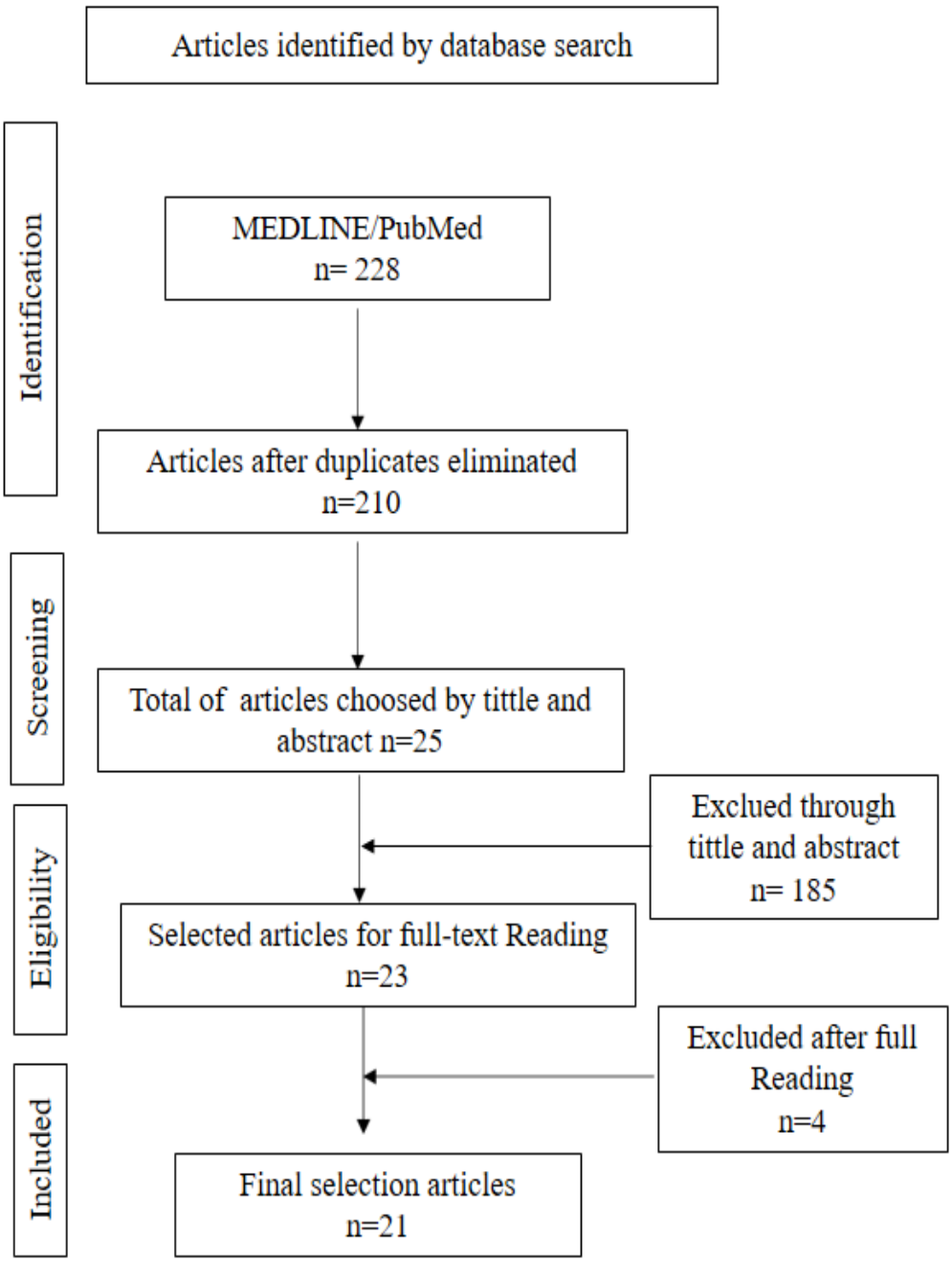

Figure 1. Schematic diagram of the research strategy

Of the 21 selected articles, 18 (85.71%) reported *in vitro* assessment of the erosion, aging, air-polishing, and wear pathways of different sealants, while three articles (14.29%) investigated *in vivo* erosion and wear behavior of different sealants. Sixteen articles tested RMS (11,12,21–26,13–20), while eight tested resin-matrix composites (4,11,18,21,22,26–28). Glass-ionomers were tested only by five authors (15,16,18,24,26) and RMGI were evaluated in eight articles (15,18,19,22,24,26,27,29). The possibility of using adhesives for sealing purposes was tested in three articles (17,28,30). The *in vitro* studies assessed the wear of sealants by brushing, abrasion, or sliding wear testing to mimic the wear in the oral cavity. Tribometer was used in a pin-on-disk with rotary movement or in a ball (or pin)-on-plate with linear movement (reciprocating sliding test). Additionally, thermal cycling or aging in acidic substances (e.g. citric and lactic acid) were performed (21,25–28,30). The degradation of the sealants was assessed by profilometry and depth or volume of wear (13,20,23,24). Image-based methods included micro computer tomography (micro-CT) (21,25,27) scanning electron microscopy and X-ray diffraction (19), and laser surface scanner (18). The three *in vivo* studies all used silicone impressions to evaluate the wear. The evaluation of the impressions was made by scanning electron microscopy (11), laser profilometry (14), or by visual comparison to a scale (29). The retrieved data from the selected articles are described in Table 1 and drawn as follow:

- Barrlett et al. (14) observed a lower wear depth in upper anterior palatal teeth of adult patients sealed with Helioseal Clear Chroma (60±440 µm) than in control non-sealed teth (110±114 µm) at nine months after application. Wegehaupt et al. (17) evaluated the effect of pre-treatment with prophylaxis pastes using bovine incisors dentine. After challenging the specimens with 12000 brushing strokes with toothpaste slurry, the authors observed the lower wear depth in specimens sealed with K-0184 pre-treated with Nupro Sensodyne (1.52±0.51 µm) or without treatment (1.52±0.78 µm). The specimens sealed with Seal&Protect pre-treated with Nupro-Sensodyne presented the higher wear depth (2.69±1.07 µm).
- Galo et al. (19) tested the wear in human molars using a tribological test. The results varied from 0.003±0.0006 mm^3 in teth sealed with Fluroshield (load 10N) to 0.006±0.0031 mm^3 in specimens sealed with Vitrimer (load 3N). The wear depth observed in studies with several restoration materials used as sealants was associated

with the abrasive material used in polishing. The lowest wear was observed with Admira Seal with ClinPro Prophy Powder (109.1±30.3 μm), and the Grandio Seal combined with AirFlow Prophylaxis Powder resulted in the highest wear depth (232.7±29.6 μm). The wear volume assessed by Pelka et al. (22) ranged from 0.18±0.04 to 0.47±0.07 mm^3, both obtained with plane specimens of Grandio Seal. The lowest values were observed when the specimens were air polished with ClinPro Prophy Powder and the highest with AirFlow Prophylaxis Powder.

- The thermal cycling and mechanical loading applied simultaneously significantly increased the microleakage of the sealants (13). For instance, the microleakage mean scores observed in human third molars sealed with Clinpro, Helioseal F and Tethmate F1 increased from 0.08±0.39, 0.76±0.95 and 0.48±0.98, respectively, when only mechanical loading was applied, to 1.92±1.15, 1.08±1.04 and 1.06±0.98 when the mechanical loading was combined with thermocycling (13).
- The integrity of the sealant was strongly affected by the combined effect of the acidic medium and mechanical action. Wegehaupt et al. (12) observed a cumulative calcium loss of 15.68 μg Ca/ml (2.95 interquartile range) in unsealed bovine mandibular incisors, while in sealed specimens, these values ranged from 0.90 μg Ca/ml (0.55) to 5.60 μg Ca/ml (4.80), using K-0184 or Optibond All-in-one. Brushing the sealant surfaces with toothpaste on two-body or three body testing resulted in increased wear compared to surfaces that were only exposed to acid (21,27).
- The size and amount of filler and organic matrix influenced the wear resistance of the sealants. The wear behavior and integrity of highly filled sealants were higher than that recorded for low filled ones (21,27). Sen et al. (27) observed a thickness variation in the unfilled sealant Light Bond, after thermocycling, around 40 μm, while in the filled Pro-Seal, the variation was below 5 μm. Hatirli et al. (26) observed a lower microleakage (1.7±0.48; score in a 3-point scale for dye penetration) in teth treated with Grandio Seal, a highly filled sealant, than in those treated with the unfilled Clinpro (2.8±0.42).
- The degree of polymerization of resin-matrix materials determined the wear resistance of the surfaces. Light-curing parameters should be controlled following the manufacturers' recommendations to guarantee the maximum performance of the materials (20).

Table 1. Relevant data from studies

Author (year) ***Purpose*** **Study design**	**Sealant** **Chemical composition**	**Method of wear**	**Results** - ***as indicated for each article*** Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
Li et al. (2019) (23) *Development a new light-curable sealant possessing suitable mechanical properties and a good fluoride release and recharge ability.* *In vitro*; Knobs 6x3mm	**Clinpro** (control): Triethylene glycol dimethacrylate, Bisphenol A-diglycidyl ether dimethacrylate, Tetrabutylammonium tetrafluoroborate, Silane treated silica; **MLC-FMMT** 20%Fluorinated Montmorillonite, Acrylamide, N-methylformamid, NaF in resin MLC (new light-curable sealant)	For wear resistance was tested with a tribometer 10N,100rpm and 500 cycles (silicon carbide green grinding paper number 400). Vickers hardness test was performed with 0.05 kg, 30s and using a Diamond indenter	**Microhardeness (HV):** Clinpro 17.9±0.3 MLC 15.9±2.3 **Wear depth:** Wear losses around 15% without differences between the tested material and control.
Hatirli et. al (2018) (26) *Evaluation microleakage and the penetration-depths of different fissure-sealant materials applied with or without enameloplasty after cycling aging.* *In vitro;* 160 mandibular third molars: 80 with enameloplasty and 80 without.	**Filtek Ultimate Flow** Bis-GMA, UDMA, TEGDMA, prokrilat resin, ytterbium trifluoride, silica nano-fillers, Zirconia nano-fillers (78.5 – 63.3) **GrandioSO Flow** HEDMA, Bis-GMA, TEGDMA, glass ceramics, silicon dioxide (80.2–65.7) **Majesty Flow** TEGDMA, Hydrophobic aromatic dimethacrylate, silanized colloidal silica and barium glass (80–62) **ClinproSealant** Bis-GMA, TEGDMA, EDMAB, BHT, TBATFB diphenylyodoniohexafluorofosfate (NA) **Fissurit FX** Bis-GMA, TEGDMA, UDMA, BHT, benzotriazole derivatives, inorganic glass ionomer filler, NaF (NA) **GrandioSeal** Bis-GMA, TEGDMA, nano fillers (70-NA) **BeautiSealant**	Samples were subjected to a two-year aging simulation using cyclic chewing, thermocycling, and brushing: Chewing using 240000 cycles, 49 N, and 102 rpm (1.7 Hz). Thermocycling 1000cycles, 5-55°C, 100s/cycle. Brushing with load 200g and 1000 strokes and 60 rpm. Wear was estimated by microleakage. It was assessed through dye penetration. Samples were immersed in basic-fuchsine (0. 5%), 24h at 37°C. Dye penetration was evaluated in sectioned teeth observed by microscopy.	**Microleakage mean scores** *Without Enameloplasty* Filtek Ultimate Flow 0.6±0.51 GrandioSO Flow 1.0±0.66 Majesty Flow 0.4±0.51 ClinproSealant 1.6±0.96 Fissurit FX 1.3±0.94 GrandioSeal 1.7±0.82 BeautiSealant 2.1±0.73 Fuji Triage 2.5±0.52 *With Enameloplasty* Filtek Ultimate Flow 0.6±0.69 GrandioSO Flow 1.5±0.52 Majesty Flow 1.2±0.42 ClinproSealant 1.5±0.85 Fissurit FX 1±0.67 GrandioSeal 1.7±0.67 BeautiSealant 1.9±0.87

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
	Giomer-based fissure sealant. TEGDMA, UDMA, S-PRG fillers (NA); **Fuji Triage** Powder: alumina-fluoro-silicate glass (amorphous); Liquid: polyacrylic acid, Specific component	The microleakage was evaluated using a score (0 - no dye penetration; 3 - extended dye penetration).	Fuji Triage 2.6±0.51
Sen et al. (2017) (27) *Test the possibility of using the modified optical coherence tomography (OCT) to measure the thickness of surface sealants* *In vitro* on 45 human teeth: premolars and third molars	**Light Bond™ Sealant** Bisphenol A diglycidylmethacrylate, triethyleneglycol dimethacrylate, urethane dimethacrylate, tetrahydrofurfuryl methacrylate, hydrofluoride methacrylate, **Opal® Seal** Bis-GMA, HPMA, ethyl alcohol, methacrylic acid, **Pro Seal®** Hexafunctional urethane acrylate, ethoxylated bisphenol A diacrylate, ethoxylated trimethylolpropane triacrylate, EDMAB, camphorquinone, silica	Thermocycling: 3000cycles, 6.5/60°C, 40s, 2s pause. Cleaning brushing 2,5N, 2000rp/min and polishing brushing with Cleanic during 25s.	**Surface thickness of sealants** *Thermocycling (or artificial aging)* Pro Seal® median 0.88 (95% CI 0.87-4.36) Light Bond ™ median 3.60 (95%CI 2.25-40.9 Opal® Seal: median 2.26 (95%CI 0.00-12.23) *Polishing (professional tooth cleaning):* Pro Seal® and Opal® Seal: 2-3µm/s of polishing; Light Bond™: 3-4µm/s of polishing.
Wegehaupt et al. (2017) (17) *Evaluation of the erosive preventive potential of a surface sealant and self-etch adhesives under abrasive conditions* *In vitro*; 90 bovine mandibular incisors	**K-0184** UDMA, trimethacrylate, PENTA, highly dispersed silica, camphorquinone, ethyl-4(dimethylamino)benzoate, BHT, Cetylaminhydrofluoride, acetone **Shield Force Plus** 2,6-di-tert.butyl-4-methyphenol,2-HEMA, Bis-GMA, diphenyl-(2,4,6-trimethylbenzoyl)-phosphinoxide, mequinol, methacryloxyalcylic acid; phosphate, propan-2-ol, TEGDMA, camphorquinone, water **Xeno® Select**	During 12 days, the samples were demineralized with 2.5 ml of HCl (pH=3). After, the samples were washed in distilled water and brushed for 5 min, with a total 7200 brush stokes (120 strokes per min. and a load of 2.5N). The samples remained overnight in artificial saliva. The wear was estimated by the loss of calcium expressed in µg	**Cumulative Ca concentration after 12 days of erosion challenge** *Results expressed as median (interquartile range)* K-0184, 0.90 (0.55) Shield Force Plus 3.19 (2.27) Xeno® Select 1.30 (0.65) Scotchbond™ Universal 1.10(0.80) Adhese Universal 1.71 (0.86) OptiBond™ All-In-One 5.60(4.80) Clearfil™ Bond 1.76 (1.01)

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
	Bifunctional acrylates, acidic acrylates, phosphoric acid ester, water, T-butanol, initiators, stabilizers; **Scotchbond™ Universal** 10-MDP, dimethacrylate resins, HEMA, Vitrebond™ copolymer, fillers, ethanol, water, silan, initiators; **Adhese Universal** 2-HEMA, Bis-GMA, methacrylate phosphoric acid ester, 2-dimethyl-aminoethylmethacrylate, camphorquinone, ethanol, water **OptiBond™ All-In-One** HEMA, ethanol, disodium hexafluorsilicate, acetone, water; **Clearfil™ Bond** Primer: 10-MDP, 2-HEMA, hydrophilic aliphatic dimethylacrylate, camphorquinone, N,N-diethanol-p-toluidine, water Bonding: 10-MDP, 2-HEMA, Bis-GMA, hydrophobic aliphatic dimethylacrylate, camphorquinone, N,N-diethanol-p-toluidine, colloidal silica	Ca/ml dissolved during the erosion challenge	
Asefi et al. (2016) (4) *Determination the wear resistance of Estelite flowable composite resin as a fissure sealant* *In vitro*; 35 disk-shaped samples	**Estelite Flow Quick** Organic matrix: Bis-GMA,UDMA, TEGDMA; Type of filler: ilica- Zirconia Supra-nano mono-dispersing spherical, %filler by weight volume: 71(53), nanofilled, Composite resin **Estelite Flow Quick High Flow** Organic matrix: Bis-GMA,TEGDMA; Type of filler: Silica- Zirconia Supra-nano mono-dispersing	Two-body wear test with pin-on-disk method. The samples were wore under a 15 N force and a 0,05m/s for a 100m distance	**Wear was measured by surface roughness with a profilomiter (expressed in wear area in μm^2).** Estelite Flow Quick 2708.9714 Estelite Flow Quick High Flow 3206.0857 Filtek P90, 3278.2142 Filtek P60, 4335.9571 Tetric N-Ceram: 4397.5714

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
	spherical, % filler by weight volume: 68(49), nanofilled; Composite resin **Filtek P90** Organic matrix: Siloxane, Oxirane; Type of filler: Quartz, % filler by weight volume: 76, microhybrid; Composite resin **Filtek P60** Organic matrix: Bis-GMA, UDMA, TEGDMA; Type of filler: Bis-GMA, UDMA, TEGDMA, %filler by weight volume: 71, microhybrid;Composite resin **Tetric N-Ceram:** Organic matrix: Bis-GMA, UDMA, and TEGDMA; Type of Filler: Glass microfiller, % filler by weight volume: 63.5, nanofilled; Composite resin		*Wear of all groups was similar, approximately 3585.35*
Galo et al. (2014) (19) Evaluation wear of pit-and-fissure sealants in contact with primary teeth *In vitro*; Human molars (permanents or primary teeth)	**Fluroshield** Urethane modified Bis-GMA dimethacrylate; Barium aluminoborosilicate glass (30%), Polymerizable dimethacrylate resin, Bis-GMA, Sodium fluoride, Dipentaerythritol pentaacrylate, Phosphate, Titanium dioxide, Amorphous silica **Vitremer** Powder: fluoraluminosilicate glass, redox catalyst system, pigments, Liquid: aqueous solution of a polycarboxylic acid, modified with pedant methacrylate groups, Vitrebond copolymer, water, HEMA, photoinitiators.	Two-body wear test performed in a pin-plate configuration with sliding movements by 4mm. Tribiological loads of 3 and 10N at a frequency of 1 Hz, 900 cycles in artificial saliva.	**Wear volume (mm^3)** *3N in permanent teeth* Fluroshield 0.005±0.0021 Vitremer 0.006±0.0031 *3N in primary teeth* Fluroshield 0.004±0.0007 Vitremer 0.004±0.0010 *10N in permanent teeth* Fluroshield 0.003±0.0006 Vitremer 0.005±0.0012 *10N in primary teeth* Fluroshield: 0.005±0.0022 Vitremer: 0.005±0.0009

Author (year) ***Purpose*** **Study design**	**Sealant** **Chemical composition**	**Method of wear**	**Results - *as indicated for each article*** Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
Yetkiner et. al (2014) (30) *Evaluation of the stability of two conventional adhesives, when combined with low-viscosity sealants, infiltrate used sealing sound enamel against toothbrush* *In vitro*; Bovine enamel discs:10 bovine mandibular incisors	**Transbond XT Primer** Bis-GMA 45 – 55%,TEGDMA 45 – 55% 4-dimethylaminobenzene etanol <0.5%, camphorquinone <0.3%, hydroquinone <0.03% **Heliobond** Bis-GMA 50–100%, TEGDMA 25–50%,Initiators – stabilizers **Icon (infiltrant)** Bis-GMA 50-100% TEGDMA 25-50% Initiators, stabilizers *The infiltrant was used in combination with the Transbond and Helibond*	Samples were stored in distilled water for 24 h at 37°C. After they were immersed in 8 ml HCl (pH=2.6) during 9 days and they were exposed to 1825 toothbrush-stokes per day with 2 N force. *The wear was estimated through the loss of calcium expressed in µg Ca/ml*	**Cumulative Ca concentration after 9 days of erosion challenge** *(values estimated from the graphs)* Control ±40 Transbond XT Primer+Icon ±23 Heliobond+Icon ±24
Korbmacher-Steiner et al. (2013) (21) *Evaluation of the performance of four sealants with different characteristics* *In vitro*; Human lower incisors and premolars; 100 samples	**ProSeal™** Ethoxylated bisphenol A diacrylate (10– 50 %), urethane acrylate ester (10 – 40 %), Polyethyleneglycol diacrylate (10– 40 %), fluoride-containing glass frit (5– 40 %) **LightBond ™** Glass filler (20 – 50 %), urethane dimethacrylate (10– 30 %), triethyleneglycol dimethacrylate (10– 30 %), hydrofluoride methacrylate (1– 3 %) **OrthoSolo ™** Alkyl dimethacrylate resins (60– 80 %), barium aluminoborosilicate glass (14–24 %), silicon dioxide (2 – 10 %), sodium hexafluorosilicate (1 – 5 %), ethyl alcohol (1 – 5 %) **Seal&Protect** Acetone (25 – 50 %), di- and trimethacrylate resins (25– 50 %), PENTA (2.5 – 10 %), Triclosane (2.5 – 1.0 %),	20 samples/treatment Brushing with 2.94 N load, 8800 oscillations per minute; 12, 18, and 24 months simulation. At every five minutes of brushing, samples were exposed to thermal stress: 70°C, 10 min, 5°C, 15 min. At each 39 min, it was immersed in an acid drink (Coca-Cola, pH=3.0).	**Surface thickness of sealants (µm)** *After 2 years of tooth brushing* *(values estimated from the graphs)* ProSeal™ ±50 LightBond™ ±0 OrthoSolo™ ±5 Seal&Protect™ ±5
Wegehaupt et al. (2013) (12)	**Seal&Protect**	Pre-treatment with prophylaxis pastes: Nupro, Nupro	**Wear depth (µm)** *Mean cumulative wear*

Author (year) ***Purpose*** **Study design**	**Sealant** **Chemical composition**	**Method of wear**	**Results - *as indicated for each article*** Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
Evaluation of the abrasive wear of surface sealants by tooth brushing. *In vitro*; 108 bovine incisors dentine	Di-and trimethacrylate resins, PENTA (dipentaerythritol penta acrylate monophosphate), functionalized amorphous silica, photoinitiators, butylated hydroxytoluene, cetylamine hydrofluoride, triclosan, acetone **K-0184** Di- and trimethacrylate resins; PENTA (dipentaerythritol penta acrylate monophosphate), functionalized amorphous silica, photoinitiators, butylated Hydroxytoluene, cetylamine hydrofluoride, acetone	Sensodyne; Treatment with sealants and 12000 brushing strokes with toothpaste slurry in an automatic brushing machine with a constant frequency of 120 strokes/min and on 2.5N.	*After pre-treatment with Nupro* Seal&Protect 2.47 ±0.52 K-0184, 2.32 ±1.03 *After pre-treatment with Nupro Sensodyne* Seal&Protect 2.69 ±1.07 K-0184, 1.52 ±0.51 *Without pre-treatment* Seal&Protect 2.63± 1.56 K-0184, 1.52± 0.78
Yun et. al (2013) (25) *Evaluation of the effect of artificial aging on the bond durability of fissure sealants.* *In vitro*; 20 bovine incisors and 12 human third molars	**Ultrasaeal XT plus** Bis- GMA 58%, filled resin, fluoride, ethyl alcohol; **Enamel Loc** TEG-DMA, urethane dimethacrylate oligomer, methacrylated phosphoric acid esters, 4-META; **Clinpro:** Bis-GMA/TEG-DMA, silane treated amorphous silica, fluoride, TiO2, rose bengal sodium **Adper Prompt L-Pop Methacrylated** phosphoric esters, Bis-GMA, 2-hydroxyethyl methacrylate (HEMA), polyalkenoic acid.	The 20 bovine incisors were sealed with the four sealants. They were submitted to the microtensile bond strength (µTBS) after 24h storage in 37°C water and after 5000 and 10000 thermal cycles between 2 water baths of 5°C and 55°C during 30s. The 12 intact human molars were sealed, and they were immersed in 50% silver nitrate solution for 24 h, followed by exposure to fluorescent light, before were scanned in a micro-CT to evaluate leakage	**Results were expressed in microtensile bond strength in MPa.** *Bovine 10000 thermal cycles*: **Ultrasaeal XT plus** 35.9±9.5 **Enamel Loc** without results **Clinpro** 26.4±15.7 **Adper Prompt L-Pop Met.** 23.2±6.2 *Human micro CT analysis- leakage evaluation* **Ultrasaeal XT plus** penetration inadequate **Enamel Loc** strong leakage after thermocycling **Clinpro** not tested **Adper Prompt L-Pop Met.** Leakage observed after thermocycling
Tripodi et. al (2011) (11)	**Saremco Microseal** BisGMA, Bis-EMA, TEGDMA, silanized silica dioxide, polymerization initiators and stabilizers	After sealing, they made a replica using replication technique: impression-based	**Results are the proportion of the original material**

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
Evaluation of the wear of different sealants materials using the replication technique *In vivo*; 10 patients (6 males and 4 females) and a total of 20 teeth (10 maxillaries and 10 mandibular	**Clinpro Sealant** Bis-GMA, TEGDMA, EDMAB, components of the photo-initiator system, silane treated with amorphous silica, tetrabutylammonium-tetrafluoroborate, titanium dioxide, rose bengal sodium **Delton FS +** 55% glass fillers, triethylene glycol dimetharcylate, BisGMA, barium alumino fluroboro silicate glass, titanium dioxide (opaque only), sodium fluoride, polymerization initiators and stabilizers, **Filtek Supreme XT** Methacrylate resin monomers, BisGMA, TEGDMA, Bis-EMA, dimethacrylate polymer	technique, and the impressions were cutter on 1 mm section and observed under a scanning electron microscopy. These measurements/impressions were taken immediately after the application of sealant, after 6 months and 1 year	After 6 months the mean of remaining material was 62.37% ±1.21 (loss around 37%); After 1 year the remaining material was 49.63±1.11 (loss around 50%); *No differences between sealants (6 mouths and 1 year).*
Bartlett et al. (2010) (14) *Investigation the application of a fissure sealant would offer longer protection* *In vivo*; 17 Adult patients with upper anterior palatal teeth	**Helioseal Clear Chroma** Composition in percent by weight: BISGMA 60.0, TEGMDA 39.3 and stabilizers, catalysts 0.7,	Metal discs (2mmx0.2mm) were cemented on the palatal surfaces. The sealant was applied to the fissures. Natural wear evaluated at 0.3,6,9,12 and 20 months.Natural wear evaluated at 0, 3, 6,9,12 and 20 months.	**Wear depth (**µm) **Control teeth** 180±270 (after 20 months) **Fissure sealed** teeth 290±500 (after 20 months) Until 9 months fissure, sealed teeth had a smaller wear 60±440 than control teeth 110±114 *There were significant differences in wear between sealed and control teeth*
Pelka et al. (2010) (22) *Evaluation of the effect of air-polishing abrasives on the wear of restoration materials used sealants*	**Admira Seal** 55.0 % weight/43 % volume **Grandio Seal** 70.0 % weight/57.4% volume **Tetric EvoCeram** 75.5 % weight/54.5 % volume, **Tetric Flow** 64.6 % weight/39.7 % volume,	The samples treated with 3 abrasives: Acclean Air Preventive Powder AirFlow Prophylaxis Powder ClinPro Prophy Powder	**Wear depth (µm)** *Acclean Air Preventive Powder*: Admira Seal 173.6±43.8 Grandio Seal 212.5±40.8 *AirFlow Prophylaxis Powder:* Admira Seal 190.6±23.6 Grandio Seal 232.7±29.6

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
In vitro; Air polishing, 180 samples: plane specimens of restoration materials	**Grandio Flow** 80.0 % weight/65.6 % volume **Ionofil Molar** 50 %weight		*ClinPro Prophy Powder:* Admira Seal 109.1±30.3 Grandio Seal 117.3±32.8 **Wear volume (mm3)** *Acclean Air Preventive Powder* Admira Seal 0.27±0.05 Grandio Seal: 0.44±0.09 *AirFlow Prophylaxis Powder* Admira Seal 0.32±0.05 Grandio Seal 0.47±0.07 *ClinPro Prophy Powder:* Admira Seal 0.03±0.07 Grandio Seal 0.18±0.04
Bürgers et al. (2009) (15) *Quantification of Streeptococcus mutans adhesion on pit and fissure sealant materials and the correlation of these findings to surface roughness and surface free energy* *In vitro*; 240 cylindrical specimens (10 mm diameter and 2mm thickness)	**Clinpro Sealant** Triethylene glycol dimethacrylate, Bisphenol a diglycidyl ether dimethacrylate, Tetrabutylammonium tetrafluoroborate, Silane treated silica, **Delton FS+** Matrix: Bis-GMA/ TEGDMA, Barium-Aluminium-F-Br-Silica-Glass, and no fluorid, filler: 53 % wt **Embrace WetBond** Di-tri multifunctional monomers in an acid-integrating network, fluoride **Grandio Seal** 70% wt inorganic fillers, monomer matrix: Bis-GMA, TEGDMA, **Guardian Seal**	The sealed materials were incubated in the *Streeptococcus mutans* suspension, 2.5h, 37° C and adhering bacteria and the surface properties were quantified before and after 1 month of immersion in distilled water, after 6 months of immersion in water and after a thermocycling performed with a thermal cycle with 5000 cycles (5°C / 55°C). Aging regime: water immersion and thermocycling.	**Roughness (µm); SEF measured in mJ** Results expressed in median (25%/75%) *After thermocycling:* Clinpro Sealant 0.15 (0.15/0.19); SFE 40.8(26.3/14.5) Delton FS+0.21 (0.19/0.27); SFE 43.9 (31.4/12.5) Embrace WetBond 0.21(0.19/0.27); SFE 38.3 (31.3/7.0) Grandio Seal 0.15(0.15/0.19); SFE 42.1(35.8/6.3) Guardian Seal 0.53 (0.38/0.72); SFE (31.9/7.4) Helioseal F 0.19(0.19/0.23); SFE 39.4(32.2/7.2)

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
	Filled 30% by weight, 14.4% by volume, fluoride-releasing **Helioseal F** Matrix: Bis-GMA, TEGDMA, UDMA. Filler: 20% wt. F-silica-glass, 21.5 % wt. Silica, and fluorid, **UltraSeal XT plus** Diurethane dimethacrylate, bisphenol A diglycidyl ether dimethacrylate fluoride **Ketac Bond** Glass-ionomer **Fuji II LC** Glass ionomer, powder: aluminosilicate glass, pigments, liquid: polyacrylic acid, distilled water, HEMA (17%), dimethacrylate monomer, camphoroquinone, **Dyract Seal** Matrix: Penta/ DMAEMA/DEGDMA Filler: St-Al-Fl-Silica Glass and fluorid,	Note: The adhering of *S. mutans* measured by fluorescence intensities.	UltraSeal XT plus 0.15(0.11/0.15); SFE 41.6 (28.9/12.7) Ketac Bond 0.44 (0.31/0.61); SFE 45.0 (31.1/13.9) Fuji II LC 0.96 (0.61/1.30); SFE 40.1(31.5/8.6) Dyract Seal 0.15 (0.11/0.15); SFE 39.1(28.9/10.2)
Koyuturk et al. (2008) (13) *Effect of mechanical and thermal factors on the microleakage of three fissure sealants* *In vitro*, 120 human third molar teeth	**Clinpro** Triethylene glycol dimethacrylate, Bisphenol a diglycidyl ether dimethacrylate, Tetrabutylammonium tetrafluoroborate, Silane treated silica: **Helioseal F** Bis-GMA, Urethane dimethacrylate, Triethylene dimethacrylate, High dispersed silica, Fluorsilicate glass Titanium dioxide, Catalysts and Stabilizers **Teethmate F1**	Mechanical loading (500000 times) was performed with a chewing simulator – 50N and 0.5 Hz (120 cycles per minute), thermocycling (10000 times) was performed with an electronic thermocycler (5°C-22°C-55°C) and mechanical loading (50000) +thermocycling (10000).	**Assessment of microleakage by microscopic observation of dye penetration (0 no penetration; 3- maximum).** *Mechanical loading* **Clinpro** 0,08±0,39 Helioseal F 0,76±0,95 Teethmate F, 0,48±0,98 *Thermocycling* Clinpro 0,30±0,80 Helioseal F 0,89±1,02

Author (year) ***Purpose*** **Study design**	**Sealant** **Chemical composition**	**Method of wear**	**Results - *as indicated for each article*** Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
	2-hydroxyethyl methacrylate, Triethyleneglycol dimethacrylate, 10-Methacryloyloxydecyl dihydrogenphosphate, Methacryloylfluoride-methyl methacrylatecopolymer, Hydrophobic aromatic dimethacrylate, DI - Camphorquinone, initiators; accelerators, dyes, other	The antagonist abrasive was stainless steel (5mm diameter).	Teethmate F1, 0,25±0,56 *Mechanical loading + thermocycling* Clinpro: 1.92± 1.15 Helioseal F 1.08± 1.04 Teethmate F1, 1.06± 0.98
Alexandre et al. (2006) (16) *Evaluation of the effect of 10% carbamide peroxide on the microhardness of pit and fissure sealant materials* *In vitro*; 20 cylindrical (diameter 4 mm, height 2mm) specimens of each tested material	**Fluroshield** Urethane modified Bis-GMA dimethacrylate, barium, aluminoborosilicate glass, polymerizable dimethacrylate, Bis-GMA, sodium fluoride, dipentaerythritol pentaacrylate phosphate, and silica amorphous (50% by weight), **Clinpro** Bis-GMA/TEGDMA resin composition, unfilled, releases fluoride **Vitroseal Alfa** Bis-GMA, ionomer glass, TEGDMA, aerosil, silanized, polymethacrylated, polymethacrylic acid, and stabilizer, silica (7% by weight,	Knobs of sealants (4x2mm) were polymerized during 40s. The samples were divided into two groups: control without treatment and storage in artificial saliva (during 24 h), and the second group bleached with 10% carbamide peroxide. The results of microhardness were obtained by Knob microhardness test used a 25 g load during 5s. *Bleaching gel agent: Clarigel Gold, Sodium benzoate, polypropyleneoxide, EDTA, carbopol, triethanolamine, carbamide peroxide, sodium fluoride, distilled water, mint flavor.*	**Microhardness (HV)** *Bleached Knobs* Fluroshield 17.42±3.62 Vitroseal Alfa 19.60±1.35 Clinpro 11.68±1.22 *Control Knobs* Fluroshield 23.98±2.12 Vitroseal Alfa 21.74±1.33 Clinpro 11.76±0.93
Schmidlin et al. (2006) (28) *Evaluation the wear resistance and surface roughness after chemical and mechanical wear of a newly*	**Tetric Flow** Bis-GMA, UDMA, triethilene glycol dimethacrylate, Inorganic filler 67.8% by weight (barium glass, ytterbium trifluoride, silicon dioxide, fluorosilicate glass)	After sealing, the samples were immersed at 37°C in 5 mL artificial saliva (pH7.6) or 5 mL lactic acid (pH=4) for up to 21 days. At 1, 2, 4, 7, 14, and 21	**Roughness (µm);** *During 21 days and with artificial saliva* Tetric Flow 0.10±0.03 Adhesive patch bond0.013±0.03

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
devised adhesive patch for sealing smooth enamel surfaces *In vitro*; Bovine lower central incisors; Knobs 7x2mm - 48 (specimens 3 groups of 16)	**Adhesive patch bond** Methacrylic groups-containing, elastic, crosslinked, urethane-based polymer material approximately 100-µm thick.	days the samples were rinsed in distilled water and received 10 double-strokes brushing cycles per day (60 cycles per minute,250g). For brushing using a 60g the abrasive slurry. After brushing, the samples were rinsed with distilled water and reimmersed in artificial saliva or lactic acid.	Control 0.04±0.01 D*uring 21 days with lactic acid* Tetric Flow 0.10±0.02 Adhesive patch bond 0.11±0.03 Control 0.033±0.15
Kim et al. (2002) (20) *Evaluation the effects of a light source, polymerization and storage time on the microhardness and wear of pit and fissure sealants* *In vitro*; cylindrical (diameter 5 mm, height 1 mm) specimens; 10 specimens for each curing time	**Fissurit F** Monomer matrix: methacrylic acid ester (Bis-GMA), urethane dimethacrylate (content 91%). Fillers: borosilicate glass, NaF; 3%corresponds to 1.3% fluoride content **Teehmate F1** Adhesive monomer MDP (10-methacryloyloxydecyl dihydrogen phosphate), fluoride, less than 10% inorganic fillers, **Apollo Seal** **Concise** **UltraSeal XT Plus** Diurethane dimethacrylate, bisphenol, a diglycidyl ether dimethacrylate fluoride.	The samples were kept dry in light-shield bottles at 37°C for 1 week. Half of the samples were then thermocycled. The rest of the samples were stored in distilled water in light-shield bottles for 30 days (37°C), followed by thermocycling 1000 times (5 ° C and 55°C), 30s. To determine the MH, a Micro Hardness Tester for 10s with a 10g load was used	**Microhardness (HV)** Fissurit F 9.22±0.86 Teehmate F1 10.54±0.99 Apollo Seal 17.09±0.73 Concise 12.92±0.67 UltraSeal XT Plus 18.83±0.44 **Wear depth (µm)** Fissurit F 740±20 Teehmate F1 840±40 Apollo Seal 720±20 Concise 700±20 UltraSeal XT Plus 640±40 *Partial results for the conditions:* *10s visible light, before storage and top surface*.
Rios et al. (2002) (24)	**Delton** Aromatic and aliphatic dimethacrylate monomers	The wear was determined through the amount of mass	**Wear depth (µm)**

Author (year) *Purpose* Study design	Sealant Chemical composition	Method of wear	Results - *as indicated for each article* Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
Evaluation the wear and roughness proprieties of glass ionomer cements used as sealants *In vitro*; 60 cylindrical (diameter 5 mm, height 3 mm) specimens	**Ketac-Molar** Powder: aluminium-calcium-lanthanum-flurosilicate glass, 5%polycarbonate acid, liquid: polycarbonic acid and tartaric acid **Fuji Plus** **Vitremer** Powder: fluoraluminosilicate glass, redox catalystsystem, pigments; Liquid: aqueous solution of a polycarboxylic acid modified with pedant methacrylate groups, Vitrebond copolymer, water, HEMA, Photoinitiators, **Vitremer ¼**	lost after brushing with 374 strokes per minute, with a load of 200 g and the roughness through the quantitative analysis of the surface	Delton 2.28±1.11 Ketac-Molar 1.52±0.42 Fuji Plus 4.12±0.69 Vitremer1.26±0.14 Vitremer ¼ 5.41±1.03 **Roughness (µm)** Delton 0.151±0.140 Ketac-Molar 0.044±0.108 Fuji Plus 0.384±0.080 Vitremer 0.089±0.116 Vitremer ¼ 0.610±0.340
Futatsuki et al. (2001) (18) *Evaluation of the wear resistance and clinical application of resin-modified glass ionomer cements as restorative or sealants* *In vitro;* 24 cylindrical (diameter 9 mm, height 2 mm) specimens	**Fuji II** Powder: fluoro aluminosilicate and liquid: methacrylated polyacrylic acid, **Fuji III** Powder: aluminium flurosilicate glass. Liquid: polyacrylic acid and 2-hydroxyethl methacrylate (HEMA **Fuji II LC** Powder: aluminosilicate glass, pigments, Liquid: polyacrylic acid, distilled water, HEMA (17%), dimethacrylate monomer, camphoroquinone, **Fuji III LC** Resin-modified glass ionomer **Concise Light Cured White Sealant** Resin-based sealant **Restorative Z-100** Bis-GMA and TEGDMA, inorganic matrix: zirconia/silica (71%)	Knobs (9x2mm) polished 1000 grift before the three-body wear test was performed by 20000 cycles with a load of 4kgf/cm^2 and slid by 2mm (simulated masticatory action) using a Load Cycling Tester	**Wear depth (µm)** Fuji II 86±8 Fuji III 154±79µm Fuji II LC 85±55 Fuji III LC 157±14µm Concise Light Cured WS 25±12µm Z-100 Restorative: 23±10

Author (year) ***Purpose*** **Study design**	**Sealant** **Chemical composition**	**Method of wear**	**Results - *as indicated for each article*** Microhardeness (HV); Wear depth (µm); Wear volume (mm^3); Roughness (µm), or other variable measured
Wu et. al (2001) (29) *Test the occlusal wear of a resin-modified glass ionomer cements* *In vivo*; 41 healthy and informed patients	**Fuji II LC** Glass ionomer, powder: aluminosilicate glass, pigments, liquid: polyacrylic acid, distilled water, HEMA (17%), dimethacrylate monomer, camphoroquinone; Combined with: 1. Visio-Bond, unfilled bonding resin 2. With Delton Opaque, opaque lightly filled resin sealant; 3. With TPH, spectrum hybrid resin composite.	Sealing the occlusal with RMGI in carious permanent molars and recall at 6, 12 and 24 months; Three sealants: One treatment sealing using a thin layer of low viscosity unfilled resin; Other treatment sealing using a thicker layer of a lightly-filled and the last treatment co-curing the RMGI using a posterior resin composite. Silicon impressions were taken, and color transparencies (1.5 magnification). The wear was quantified using the Vivadent Scale. Extensive occlusal cavities were excluded	**Wear depth (µm)** Fuji II LC median 100 Fuji II LC median 25 Fuji II LC median 25

4. DISCUSSION

4.1. Teeth occlusal sealants

Currently, the two main types of occlusal sealants are composed of resin-matrix composite and glass-ionomers as seen in Table 1 (3). The manipulation of the materials, mechanical properties, and wear resistance are highly dependent on their composition (9).

Conventional Glass-Ionomers consist of two components, a basic fluoro-aluminosilicate glass powder (ion-leachable) and an aqueous solution with polyalkenoic acids, which are carboxylic acids (6,7). The glass component is prepared by sintering mixtures of powdered silica (SiO_2), alumina (Al_2O_3), cryolite (Na_3AlF_6), aluminum trifluoride (AlF_3), fluorite (CaF_2) and aluminum phosphate ($AlPO_4$) at 1100−1500°C. Nowadays, some brands include zinc, lanthanum, strontium, or calcium fluoroaluminosilicate (31). Polyacrylic acid is the main substance of the polyalkenoic acids in the aqueous solution although tartaric and maleic acid as well as homo- or co-polymer of acrylic acid can be found (7,32,33). The polymer affects the properties of GI since higher polymeric molecular weights increase the strength of the glass-ionomer. Optimum properties are gathered with molecular weights between 11,000 and 52,000 and therefore the powder-liquid ratio determines the physical properties of GI (7). Thus, the viscosity, strength, and wear resistance increase in function of the amount of powder. Viscosity influences the material flowability throughout the teeth occlusal pits and fissures (24). The application of GI is a technique well established in dentistry. When it is previewed that the sealed surface is subjected to low stress it is an adequate choice, since it presents a good adherence to the tooth and fast setting, and do not need the polymerisation process that are necessary for resins (31,34). GI chemically bond to enamel and dentin tissues due to the acid-base reaction and via formation of carboxylic groups (-COOH) (1). The compressive strength of GI was recorded at around 122-162 MPa, tensile strength 4.2-5.5 MPa, and elastic modulus at around 11.2 (34).

Resin-Modified Glass-Ionomers include the components of conventional GI, photoinitiators (camphorquinone) and methacrylate-based monomers . The strength of RMGI is higher than that of conventional GI but the biocompatibility of RMGI is lower due to the presence of monomers (3,32,33). The polymerization reaction of RMGI begins by photoactivation of the camphorquinone which initiates the chain monomers' reaction, followed by the acid-base

reaction of the ionomer component (1). Nowadays the use of RMGI is common in dentistry. The easy application and the proprieties of the material, namely the flowability and the possibility of polishing after complete polymerisation has made these material the first choice of several dentists. The main disadvantage of these RMGI is the need for photopolymerisation, that causes some discomfort in the patients, and the inherent risk of incomplete polymerisation. A weaker bond between the fillers particles and the organic matrix of the RMGI is reported in comparison to the resin-matrix composites (9). That weaker bond negatively affects the strength and wear resistance of the ionomer sealants (Table 1). RMGI has a low compressive strength in the range of 40-141 MPa, while the elastic module was recorded at 2.5-7.8 GPa and tensile strength at 13-24 MPa (34). The variability of the values can occur due to chemical reaction method and the presence of defects like pores and micro-cracks. The ideal glass ionomer should have a high compressive and tensile strength while the elastic modulus should be closer to that of dentin (34).

Resin-Matrix sealants are materials containing an organic matrix reinforced or not with inorganic fillers. The organic matrix includes a combination of methacrylate monomers such as bisphenol A-glycol dimethacrylate (Bis-GMA), urethane dimethacrylate (UDMA), Triethylene glycol dimethacrylate (TEGDMA), HEMA, and ethoxylated bisphenol A dimethacrylate (Bis-EMA) (26). The filler particles can reach a weight percentage from 10% up to around 75%. The filler material can be: barium silicate, colloidal silica, strontium silicates, or zirconium silicate particles (3,10,35,36). Two size particles are often used at micro-scale (0.4-10 μm) and nano-scale (20 to 40 nm) (37). The incorporation of nano-fillers at a higher percentage increase the strength and wear resistance of the materials although that can affect the flowability into the pits and fissures (38). The physical proprieties of resin matrix material are, among others, the compressive strength that can reach values between 179-225 MPa while the tensile strength was recorded at around 34-37 MPa, flexural strength at 80-220 MPa, and elastic modulus at 4.5-9.8 GPa (Table 1) (33,34). The physical proprieties of the resin-matrix materials are highly dependent on the chemical composition of the organic matrix and size and percentage of fillers. The advantages of RMS are the easy application and the ability to seal small fissures due to its low viscosity. The preparation is very easy, once it is not necessary to combine different materials, but they need photopolymerisation, that can be its main disadvantage (33,39,40).

4.2. *In vivo* studies

The *in vivo* evaluation of occlusal pit sealant surfaces involved studies in human participants that required teeth impression techniques (11,14,29). None of the studies used intra-oral digital scanning to evaluate the *in vivo* wear. Findings are described in Table 1 and the methods and main outcomes are discussed as follow.

An *in vivo* study assessed potential benefits of three combinations of the RMGI Fuji II LC (aluminum fluoro–silicate glass and a modified polyacrylicacid matrix crosslinked by poly HEMA) with resin-matrix sealants due to the high wear of RGMI sealants (29). The study involved 41 healthy human participants with carious teeth. Occlusal cavities were filled with Fuji II LC in which one group was coated with a Visio-Bond layer and another group was veneered with TPH Spectrum hybrid resin composite. Silicone impressions were carried out after the application of the sealants and at different follow-up time points: 6, 12, and 24 months. Worn surfaces were analysed by the morphological aspects of the elastomeric impressions (29). The authors concluded that the application of a thin layer of low viscosity resin (Visio-Bond) did not show any protective effect although a thick layer of a lightly filled RMS (Delton Opaque) revealed a decreased wear. However, the layer should be replaced, since after 18 months a major or total loss of the sealant material occurs. The surfaces coated with resin-matrix composites showed the lowest wear rate which can be a solution for long-term occlusal sealing, but only when a thick layer was applied. (29). Another study involved ten children with ages from 7 to 9 years old (11). Ten maxillary or mandibular caries-free teeth were filled with four commercial resin-matrix sealants as seen in Table 1. Impressions with silicone were performed after the occlusal sealing, and at two different follow-up time points: six months and one year. Silicone impressions were cross-sectioned at 1 mm sections from vestibular-buccal to the lingual axis and analysed by scanning electron microscopy (SEM). The depth of the central groove was identified and analysed regarding the materials and time points. Six months after the application, approximately 62% sealant materials remained in the occlusal teeth. Nevertheless, the remnant percentage of sealant materials decreased down to 49% after one year. All four material tested had only one common component, the Bis-GMA. The other components were variable among the commercial formulations tested (11).

A previous study evaluated the *in vivo* wear performance of a RMS involving 17 adult participants regarding more long term occlusal protection (14). The method used by these authors included cementation of 2x0.2 mm stainless steel disks on the palatal surfaces of all upper first molars. Randomly chosen first molars were sealed with Helioseal Clear Chroma. Those teeth had variable enamel exposure, assessed by the Smith and Knight Tooth Wear Index (TWI) (16).Patients were examined at different follow-up time points: 3, 6, 9, 12, and 20 months. At baseline and revisions, they token silicone impressions were carried out at the determined time points and analysed by using an optical profilomiter. Considering all the teeth involved in the study, the sealing revealed to be a good strategy to prevent wear, once the wear depth was smaller in sealed teeth until 9 months follow-up. After 9 months, the situation changed and therefore the sealed teeth revealed a severe wear when compared to the control group. Also, the authors treated separately only results from the teeth attached with the stainless steel disks for the final time point of the study. In these cases, the wear on the control group was higher (140 ±114 µm depth) when compared to the test group (30 ±250 µm) suggesting that the sealing had a protective effect although a large standard deviation in the wear depth values was noticable (14).

4.3 *In vitro* studies

In the present revision, from the 21 articles considered, the majority involved *in vitro* studies (4,12,22–28,30,13,15–21). There was a great variety of methods used to challenge the material wear and to assess the wear. In the results section, it is presented a synthesis of the methods used by the authors. The methodology was diversified both on challenging method and parameters used, and in the assessment of wear. That difficults the comparison of results between articles in Table 1.

Futasaki et al. (18) and Rios et al. (16) observed no differences between the wear resistance of conventional and resin-modified glass-ionomer. They used different methods to challenge the material and to assess the wear. The first used knobs of two GI (Fuji II and Fuji III) and the correspondent RMGI and challenged the knobs by vertical application of a 4 kgf/cm^2 with 2 mm of sliding. The surface of the impressions on vinyl polysiloxane were laser scanned, and the wear was registered. The second tested knobs made from the sealing

material, but the authors evaluated the wear through the amount of mass lost after brushing with 374 strokes per minute, with a load of 200 g and the roughness through the quantitative analysis of the surface.

Futasaki et al. (18) revealed that the resin component did not enhance the glass ionomer wear resistance, and the RMGI powder/liquid ratio and conventional glass ionomer have more influence on the wear result. However, in more recent studies, the resin-matrix sealants showed better wear resistance than the RMGI. In general, RMGI revealed better mechanical properties than the conventional glass ionomers (9,41). Rios et al. (24) concluded that flowable GI (Vitrimer ¼ and Fuji plus) were worst than the restorative GI (Ketac-Molar and Vitrimer) or RMS (Delton). The higher wear depth they observed was with Vitrimer ¼ with 5.41±1.03 % on depth reduction. The authors did not found differences between the restorative GI and the RMS.

Galo et al. (19) demonstrated that the GI sealant does not have a homogeneous distribution of the charged particles like the RMS, and the structure of the resin sealant showed less loss of particles and less wear compared to the GI sealant. This sealant, on the contrary, showed more loss in the filler particles and higher wear (19). In the wear process, resin-matrix materials undergo polymeric chain cleavage to form oligomers and monomers, while glass ionomers show complex absorption, external ion transport, and disintegration (32).

Korbmacher-Steiner et al. (21) studied the wear performance and integrity of two high filled sealants (ProSeal and Light Bond) and two low filled sealants (OrthoSoloand Seal&Protect). They applied the sealants in one hundred human teeth without caries, previously prepared to wear challenge. The sample was divided into five groups, one control without sealant and four with sealants. The challenge consisted of a toothbrush-dentifrice abrasion using a device newly developed that provided motions, pulsations, and oscillations, with a vertical load of 300 g. They applied the dentifrice mixed with distillate water, and cooled down the challenged teeth with cold NaCl solution. The abrasion was intercalated with a chemical challenge, by immersing the teeth in Coca Cola, and thermal stressing (70°C, 10 min to 5°C, 10 min). The challenge planned by the authors aimed to simulate two years of natural wearing. At the baseline, and 1, 1.5 and 2 simulated years, they collected five specimens to analyze. They used microcomputer tomography to assess sealant thickness and light

microscopy to evaluate the integrity of the sealant, using a 5-point score. They concluded that the highly filled sealants performed better than the lightly filled. They also conclude that the mixed method for challenging, involving brushing, chemical and thermal stress should be tested to assess the wear of sealants, once all of them contribute to the film integrity and thickness.

The polymerization of resins is a crucial aspect to guarantee its best mechanical properties. To test the influence of the type of light used in the curing of resins (conventional visible light and plasma arc light), Kim et al. (20) planned an experiment where they combined the effect of the curing light with the polymerization time and storage time on hardness and wear of sealants. They prepared knobs with the five RMS tested, Fissurit F, Teethmate F1, Apollo seal, Concise, and UltraSeal XT Plus. The curing light was applied at specified intervals. Specimens were stored at 37°C for one week until being submitted to 1000 cycles of thermocycling. The Vicker's hardness was measured on both surfaces of the knob. The erosion wear was challenged by 10 min moving over a 600-grit SiC paper under 600 g load. The height of the specimen was taken before and after the erosion wear challenge. The authors concluded that the plasma arc light was more active on curing, once it takes less time to get similar results, and with some materials to achieve better results in the bottom face of the knobs. The authors found microhardness values between 9.22±0.86 and 18.83±0.44 (HV) for Fissurit and UltraSeal XT Plus, respectively. Curiously it was not found any correlation between hardness and wear.

Another strategy used in research is to evaluate the wear indirectly, measuring the microleakage. Hatirli et al. (26) evaluated the microleakage and penetration depth of eight materials, six resins, three RMS (ClinPro, Fissurit FX and GrandioSeal) and three composite resins (Fitek Ultimate Flow, Grandioso Flow, and Majesty Flow), one GI (Fuji Triage) and one RMGI (BeautiSealant). They used 160 humans mandibular third molars (80 with enameloplasty and 80 without). The specimens treated with the respective sealant were subjected to a two-year aging simulation using cyclic chewing, thermocycling, and brushing. The wear was estimated after immersing the specimens in 0.5% fuchsine and microscopic observation of sections of the teeth. The microleakage of the material and the penetration ability of the material were scored in scale applied by two independent

researchers. The authors concluded that the enameloplasty enhanced the penetration of the sealant. The flowable sealants had the best penetration, and glass ionomers had the worst. The penetration of sealants is highly dependent on its viscosity. The lower the viscosity, the higher the penetration. However, low viscosity ones are more sensitive to wear (40). It was demonstrated that the wear of resin-matrix products decreases as the volumetric percentage of inorganic particles increases (7,42,43). Also, the high inorganic content decreases the organic matrix volume, leading to a reduction in polymerization shrinkage and the material thermal expansion coefficient. The space between the particles that exposes the organic matrix also influences physical properties and wear. The studies indicated that the critical distance between the particles in the structure is 0.1 to 0.2 μm to protect the material against wear, so the chemical composition of the polymer matrix is a determining factor in the wear rate (4,37). Thus, changing the monomers' proportion and the fillers' composition affects the viscosity and mechanical properties of the sealants (26).

There are three ways to increase the viscosity of resins: increasing the content of the filler, using fillers with irregular shapes, and incorporating glass fibers (4). The addition of silica microparticles or vaporized inorganic glass provides rigidity and improves wear resistance, changing the structure from unfilled sealant to filled sealant or flowable composite (4,15). The use of spherical vacuum fillers can increase the load content and the fracture resistance. Also, the round shape of the filler results in less friction because of the interactions between the filler particles or the matrix and the filler particles compared to irregular filler shapes used in most flowable composite resins (4). *In vitro* wear tests in previous studies corroborate this information and indicate that the composites having spherical particles with 0.2 μm diameter or smaller present best wear resistance than composites with larger inorganic particles (37,43).

4.4. Wear pathways and assessment

Wear is a complex tribological process that results in material loss due to the friction of two surfaces. The wear can be classified in adhesive wear, abrasive wear, wear due to fatigue, and wear due to chemical action of the environment (32). The adhesive wear is a consequence of the vertical contact and sliding between the upper and lower teeth. The

forces applied may provoke a transference of material from one surface to the other, and eventually, they are frequently lost in groups of particles formed. The formation of these particles through the adhesive war may contribute to abrasive wear. Once the saliva has a vital lubricant role, this type of wear is not the most important on the wear occurring in sealing materials (44). When the sealant suffers abrasive wear, parts of material detaches from the surface due to the action of hard particles embedded in one or both surfaces of the opposite teeth. It is possibly the most critical wear mechanism. The fatigue wear results from the continuous application of loading and relaxing. With time the cyclic loading might lead to the occurrence of microcracks in the surface or below. The corrosive wear results from the chemical interaction between the sealant material and the mouth environment. Chemicals from drinks, produced by the mouth microbiota or present in the saliva are the main vehicles of chemical wear of sealants (39).

According to the American Society of Materials (ASM), there is a wide range of parameters that influence the wear mechanisms, including the material itself, the shape, the contour of the antagonist, the roughness, the movement, and its frequency, the loading rate, lubrication and the surrounding environment (8). The oral cavity is a complex environment in which acidic substances, saliva, corrosive substances, glycoproteins, and oral biofilms can be retained in the retentive micro-regions and surfaces of restorative materials. The properties of the bolus (volume, elastic modulus, hardness, viscosity) and the patient's condition (muscle activity, sex, age, weight, presence of other restorative structures) influences the mean strength of mastication, and this strength can vary from 10 to 150 N (19,20,45). Once the quality of the sealant application is determinant to reduce its wear, we should also consider the operator's quality and skills (39).

In the oral cavity, the main mechanisms of wear are abrasion, three-body abrasion, attrition, fatigue, adhesion, and erosion, or any combination of the above (8). The classification of *in vitro* wear testing is based on the type of movement (reciprocating, rolling, impact oscillation, and flow) or on the pathways (8,13). The intraoral wear mechanisms are similar to the two-body test, the three-body test, or a combination of both tests. In the two-body wear test with saliva only and in the three-body wear test with the introduction of toothpaste and food (20).

There are several methods (mechanics, thermal, chemicals, and the use of abrasives) to assess and measure the wear that dental materials are subjected to in the oral cavity, as shown in Table 1. However, the high number of variables influencing the wear and the lack of clear standards for its characterization, make it difficult to validate *in vitro* with *in vivo* results (8,11,13,16,20,24). The wear tests do not exclusively measure intrinsic material properties, but its interaction with the movement and the environment in a challenge test (8).

Microhardness is an important property to be evaluated in materials subject to wear and tear that can be evaluated by various tests such as the Brinell hardness test, Rockwell hardness test, Vickers hardness test, and Knob hardness test The Vickers Hardness (HV) test is the most common. It is performed on a micro-indenter hardness tester with the Vickers diamond indenter. A specific force is applied over a while over the samples. The diamond Vickers indenter creates a square impression of which two diagonals are projected on the surface and measures (8,10). Other properties evaluated in the tests are the wear depth and the wear area or volume. They are usually evaluated by laboratory tests like the pin-on flat (reciprocating sliding test) or, for example, the pin wear test on the disc, performed in samples with average load ranging from 5 to 50 N (the values of the masticatory force vary between 3 and 150 N), frequency from 1 to 4 Hz and a displacement of 0.3 to 6 mm at until 500,000 cycles in distilled water or artificial saliva at 25-55 °C (Fig. 2). The morphological aspects of the worn surfaces are observed and analyzed by Scanning Electron Microscopy (SEM), optical profilometry, or 3D laser scanning (45). The roughness and thickness of the sealant are also properties evaluated and measured in the wear tests.

Thermocycling is commonly used combined with mechanical loading, through the use of the chewing simulator and other methods to simulate the oral cavity conditions. Thermocycling and mechanical loading are the most common wear methods used to simulate *in vitro* stress that resin materials undergo (13). Bürgers et al. (16) showed that thermocycling and artificial aging augmented surface roughness values and declining Surface Free Energy (SFE).

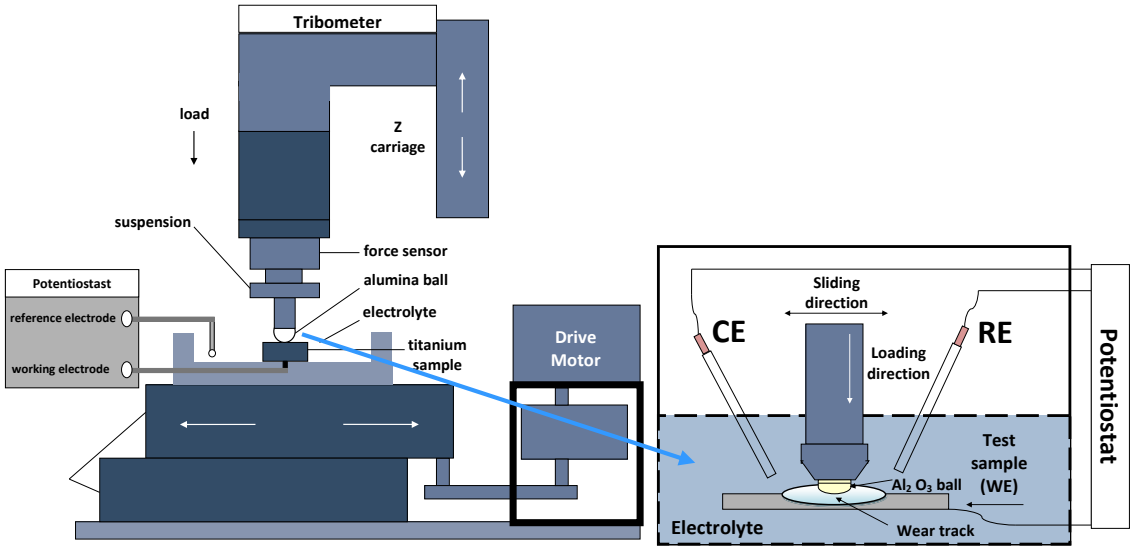

Figure 2. Schematic drawing: wear testing apparatus

Glass-ionomers are naturally brittle materials. If during the preparation of GI, there are flaws, in the surface or the inner part, it triggers cracking. When these cracks experience any kind of load, it propagates rapidly, and fractures on the material became irreversible. These phenomena are the main pathway involved in GI wear (46).

The wear resistance of resins depends on the size, volume, form, distribution, mechanical properties, the content of inorganic fillers, and the composition of the polymer matrix (4,37). The size of the filler is related to mechanical properties and surface smoothness (23). Filled sealants have a higher resistance to wear; however, their ability to penetrate pits and fissures is low. This type of sealant requires occlusal adjustments, which increase the clinical procedure (1). The wear of resin occurs through some possible pathways: resin matrix wear, loss of inorganic particles by failed bonding to resin matrix, loss of material by the ejection of inorganic particles, loss of material due to fissure propagation and fracture of the matrix and exposure of imprisoned air bubbles (9,41) as well as by abrasion or fatigue of the material (37).

In the *in vivo* studies included in this revision, all the three articles used impressions of the patients' treated teeth to evaluate the wear. The methodology used to evaluate the impression was quite different. Wu et al. (29) used the more basic technique, which consisted of visually comparing the impression with a scale. This technique has a

considerable level of incertitude due to the bias introduced by the researcher scoring the impressions. On the other hand, Tripodi et al. (11) and Barlett et al. (14) evaluated the impression using more precise techniques. The first analyzed the images obtained by scanning electron microscopy that enabled them to estimate the wear of the material more precisely, and the second, using a laser profilometer, that allowed them to measure the wear with high precision. Furthermore, Barlett et al. (14) followed a good research practice of evaluating the repeatability of the measuring technique by making a duplicate impression on ten patients.

In the reviewed *in vitro* studies, there was a myriad of combinations of methods to challenge the wear and to assess it in a very diversified pool of material. Thus, any comparisons or extracting any robust conclusion is almost impossible. Quoting the ISO/TS 14569-2 (47) **"**As a consequence, many wear tests have been proposed in dental science. Most of them consider mainly one specific aspect of the different mechanisms; some even claim to be able to characterize the wear resistance of dental materials completely. However, these procedures are not comparable because of the different wear mechanisms considered, and no generally accepted method exists". This standard is one among others that establish guidelines to challenge and assess the wear. Nonetheless, from the 21 articles reviewed in the present study, or even in the 18 *in vitro* studies, none used or made any reference to the ISO methods. In the present revision, several authors used tooth brushing, which methods the ISO standardized, but, when challenging the materials, each author followed a specifically chosen method, that hinders the comparison between material in different experiments.

The main findings of the present revision are in clear concordance with the summary presented by Heintze et al. (44) that are concerned with different laboratory methods, following different concept and measuring different phenomena as well as to the use of non-validated methods, resulting in low reproducibility and high variability.

The articles using different materials with the same wear challenge and assessment procedure did not evidence any category of material as having better performance than others. Studies using more than one sealant from each category show that different sealants from the same category might have different wear resistance. The differences

between sealants from the same category might be higher than those between sealants from different categories (15,21).

5. CONCLUSION

In the present review, relevant articles described significant outcomes on wear pathways of occlusal fissure sealants. The results of the studies allow us to conclude:

- The wear of GI sealants depends on the powder-liquid ratio. A more significant amount of powder leads to higher viscosity, less solubility, and more resistance. The supplementation of GI with resin had variable results. In some studies, the RMGI wear was similar to conventional GI, and in other, the RMGI wear was superior.
- The wear of RMS depends on the size, shape, volume, type of filler particles, filler content, the composition of polymer matrix, and distance between the particles exposing the organic matrix. Unfilled sealants showed generally higher wear than filled ones.
- From the analysis of the results of the reviewed articles, it was not possible to infer that RMS has less wear than GI.
- The studies used different methods to simulate the wear in the oral cavity, such as mechanical, chemical, thermal, and tests based on the mechanism or movement type. These methods evaluated different properties of the materials such as microhardness, roughness, microleakage, the thickness of sealant, and loss of volume and depth. These differences in challenging wear and in collected variables hinder any comparison and possibility of data extraction.

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