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Wear of resin-matrix composites used for attachments on orthodontic aligners: An Integrative review

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Wear of resin-matrix composites used for attachments on orthodontic aligners: An Integrative review

Trabalho realizado sob a Orientação do Professor Doutor Júlio Souza

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Resumo:

Objetivos: O objetivo deste estudo foi realizar uma revisão integrativa da literatura sobre o desgaste de fixações (*attachments*) e alinhadores ortodónticos estéticos.

Materiais e Métodos: Uma pesquisa eletrônica bibliográfica foi realizada nas bases de dados da PubMed (via National Library of Medicine) e ScienceDirect, usando as seguintes combinações de palavras-chave: *wear, attachment, orthodontic, surface damage, Invisalign* e *aligner*. Foram incluídos artigos publicaudos em língua Inglesa até janeiro de 2021 sobre a avaliação do desgaste de resinas compostas utilizadas como fixações (*attachments*) em alinhadores ortodônticos estéticos.

Resultados: A busca nas bases de dados PubMed e ScienceDirect resultou em 7141 artigos identificados que, após a retirada das duplicatas e análise dos títulos e resumos, resultaram em 16 artigos selecionados para compor este trabalho de revisão. Devido ao desempenho dos *attachments* sob forças oriundas do dispositivo alinhador, micro-movimentos e forças de fricção ocorrem nas áreas de contacto o que resulta em desgaste das superfícies de resina composta. Como resultado do desgaste, a diminuição da área de contato é alterada ou diminuída tendo como consequência a alteração na magnitude de forças aos dentes na direção programada. O desgaste pode ainda resultar em libertação de detritos da matriz orgânica das resinas composta como é o caso do Bisfenol A (BPA) conhecido por sua toxicidade localizada e sistémica. O nível de perda de material e libertação de moléculas tóxicas depende ainda da proporção e tipo de matriz orgânica existente na composição química das resinas compostas atuais.

Conclusão: As resinas compostas atuais usadas para fixação de alinhadores estão sujeitas a um desgaste progressivo devido aos micro-movimentos nas áreas de contato durante o tratamento ortodôntico. O desajuste, perda de material e libertação de moléculas na cavidade oral são consequência do processo de desgaste.

Palavras Chave: *attachment*; *wear; surface damage; aligner; Invisalign.*

Abstract:

Purpose: The aim of this study was to conduct an integrative review on the wear of attachments and orthodontic aligner surfaces.

Materials and methods: An electronic search was performed on PubMed (via National Library of Medicine) and ScienceDirect, using the following combination of key terms: wear, attachment, orthodontic, surface damage, and aligner. Articles published in English language until January 2021 that evaluated the wear of composite resins and the wear of attachments used for orthodontic aligners were included.

Results: The electronic search in PubMed and ScienceDirect databases identified 7141 articles. After removing duplicates and analyzing titles and abstracts, 16 studies were selected for this review. Regarding the performance of the attachments under forces from the aligning device movement, micro-movements and friction forces occur at the contact areas, which results in wear of the resin composite surfaces. As a result of wear, the contact area is altered or decreased, resulting in the magnitude change of forces onto the teeth in the planned direction. Wear can also result in the release of debris from the organic matrix of resin composite, such as Bisphenol A (BPA) which can cause localized or systemic toxicity. The degree of material loss and release of toxic molecules also depends on the proportion and type of organic matrix existing in the chemical composition of current resin composite.

Conclusions: Current resin composites used for orthodontic aligners are subject to progressive wear due to micro-movements at the contact areas during orthodontic treatment. The misfit, loss of material, and release of toxic molecules in the oral cavity are the major issues from the wear process.

Key words: attachment; wear; surface damage; aligner; Invisalign.

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FIGURE LEGENDS

TABLE LEGENDS

LIST OF ABBREVIATIONS

Bis-EMA	Bisphenol A diglycidyl methacrylate ethoxylated
Bis-GMA	Bisphenol A diglycidyl methacrylate
CAD	Computer-aided design
CAM	Computer-aided manufacturing
mm	milimeter
N	Newton
NiTi	Nickel Titanium
nm	nanometer
TEG-DMA	Triethylene glycol dimethacrylate
UDMA	Urethane dimethacrylate
µm	micrometer

INTRODUCTION

The number of patients claiming orthodontic treatment has increased in the last years although the use of metallic orthodontic devices has shown resistance by adult patients due to aesthetic and social factors (1,2). The emergence of orthodontic clear aligners has resulted in an increased demand for aesthetic appliances (2–4). The orthodontic treatment with clear aligners is based on the sequential use of removable trays for gradual alignment for 1 or 2 weeks (1,2,4,5,9). Orthodontic aligners can be manufactured by 3D printing of thermoplastic polymers such as polyurethane (4,5,7,8). Three-dimensionally printing techniques have evolved on the development of new software for digital planning associated with the printing technology (2,9). Orthodontic treatment with clear aligners are based on tooth movement at low intensity and continuous forces to achieve clinical outcomes following biological principles (10). However, the use of orthodontic clear aligners has been recently established (4,5) and there is still concerns on the precision of tooth movement due to the following factors: anchorage (5); control of the occlusal plane and vertical dimension; anterior torque and inclination of the teeth in the extraction sites.

Currently, a well-known commercial orthodontic clear aligner system is named Invisalign^{TM} (Invisalign, USA) which is composed of polyurethane from methylene diphenyl diisocyanate and 1,6-hexanedial (23). Also, the use of the accessories increases the transmission of forces on distal movements and incisor torque. On the orthodontic movement with the use of clear aligners, an adequate correct distribution of forces is required with the use of attachments on the buccal surface of the teeth (2,9) (1,3,9,11) (7). Attachments for orthodontic clear aligners are clinically built by using resin-matrix composites which are composed of a mixture of monomers (i.e., Bis-EMA, Bis-GMA, UDMA, TEDGMA) and inorganic fillers such as colloidal silica, barium silicate, zirconium silicate, or zirconia particles (16))(17) (18) (13).

An average moment of force was recorded at 7.9 N.mm under the use of power ridges and at 6.7 N.mm with the use of attachments (23). In addition, a decrease in intrusive movement has been reported. On distal movement without attachment, an initial average force in the direction of movement was recorded at 0.8 N without attachment while a force of around 1.1 N was recorded with attachment (28)(29). On intrusive vertical movement, an average force was recorded at 0.5 N without attachment while an average force of around 0.7 N was recorded without attachment (28)(29). On orthodontic loading, micromovements occur on the contacting surfaces between the attachments and the orthodontic clear aligners. That generates friction on the surfaces and therefore wear can occur depending on the loading magnitude, movements, chemical composition, and mechanical properties (i.e., hardness, elastic modulus, and strength) of the orthodontic materials. The wear is increased on the daily placement and removal of the orthodontic clear aligners by the patients. The friction and wear can cause the loss of material and changes on the design and volume on both attachment and clear aligner (7,9,11). That can result in significant changes in the distribution and direction of forces during the orthodontic treatment.

Objective and hypothesis

The aim of this study was to conduct an integrative review of the literature on the wear of attachments and orthodontic aligner surfaces. It was hypothesized that the placement and removal of orthodontic aligners as well as the micro-movements under orthodontic treatment do generate high friction and wear on the contacting surfaces of the orthodontic attachments and aligners.

MATERIALS AND METHODS

Information sources and search strategy

A bibliographic review was performed on PubMed (via National Library of Medicine) and ScienceDirect (Elsevier) considering such database includes the major articles in the field of dentistry and biomaterials. A literature search was using the following combination of search terms: ((wear) AND (attachment)) AND (orthodontic); ((surface damage) AND (attachment)) AND (orthodontic); ((wear) AND (attachment)) AND (aligner); ((surface damage) AND (attachment)) AND (aligner). Also, a hand-search was performed on the reference lists of all primary sources and eligible studies of this systematic review for additional relevant publications. The inclusion criteria involved articles published in the English language, from February 2010 up to May 2021, reporting wear or surface changes of orthodontic attachments and clear aligners. The eligibility inclusion criteria used for article searches also involved: articles written in English; in vitro testing; meta-analyses; randomized controlled trials; and prospective cohort studies. The exclusion criteria were the following: papers without abstract; case report with short follow-up period; articles that did not evaluate the wear of neither orthodontic attachment or clear aligners. Studies based on publication date were not restricted during the search process.

Study selection and data collection process

The selection of studies was carried into three steps. At first, studies were scanned for relevance by title, and the abstracts of those that were not excluded at this stage were assessed. Two of the authors (JCMS, VSAL) independently analyzed the titles and abstracts of potentially relevant articles. A third author (BH) intervened in cases of disagreement. The total of articles was compiled for each combination of key terms and therefore 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 second step comprised the evaluation of the abstracts and non-excluded articles, according to the eligibility criteria on the abstract review. Selected articles were individually read and evaluated concerning the purpose of this study. At last, the eligible articles received a study nomenclature label, combining first author names and year of publication. The following factors were retrieved for this review: authors' names, journal, publication year, purpose, type of clear aligner, chemical composition of the attachment and main outcomes. A form was prepared to answer the following focused question: " Is there any wear or volume change on either orthodontic or clear aligner?" PICO question was adjusted to the issue where "P" was related to the patients or specimens while "I" referred to the methods of analyses, "C" for comparison of results, and "O" for the main outcomes. Data of the reports were harvested directly into a specific data-collection form to avoid multiple data recording regarding multiple reports within the same study (e.g., reports with different set-ups). This evaluation was individually carried out by two researchers, followed by a joint discussion to select the relevant studies.

RESULTS

A total of 7141 articles were identified on PubMed and ScienceDirect databases, as shown in Fig.1. After removing duplicates, 1027 articles were evaluated by titles and abstracts regarding the inclusion criteria. Most of articles were excluded due to the lack of information on the wear of orthodontic attachments and clear aligners. At last, 16 articles were selected for full considering the purpose of the present review. Of the selected articles, 11 (68.75%) studies were classified as in vitro while 3 (18.75%) studies involved randomized clinical trials. Six (37.50%) studies analyzed the commercial trays Invisalign^{TM}, while 3 (18.75%) studies evaluated vacuum thermoformed aligners and one (6.25%) study assessed Angelaligner^{TM} (Wuxi EA Medical Instruments Technologies ltda, China). Five (31.25%) studies assessed wear pathways of resin-matrix composites. The main results from the selected studies (Table 1) can be drawn as follow:

- Two studies reported no clinical differences between different resin-matrix composites used to build orthodontic attachments for clear aligners (11) (12) (7,11–18). However, two studies reported a moderate degree of damage on resin-matrix composites (13,24);
- Orthodontic clear aligners (Invisalign, CA Clear Aligner, and F22) evaluated by scanning electron microscope revealed an adequate fitting on anchorage attachments (14). Nevertheless, one study reported an increased degradation of the clear aligner trays over the first week of treatment (7);
- The coefficient of friction and wear volume of resin-matrix composites vary depending on the type, size, and content of inorganic fillers (16-18). For instance, resin-matrix composites with a high filler content and nano-scale size showed an increase wear resistance (16-18) that can maintain a stable design and contacting surfaces onto orthodontic clear aligners (13,14).

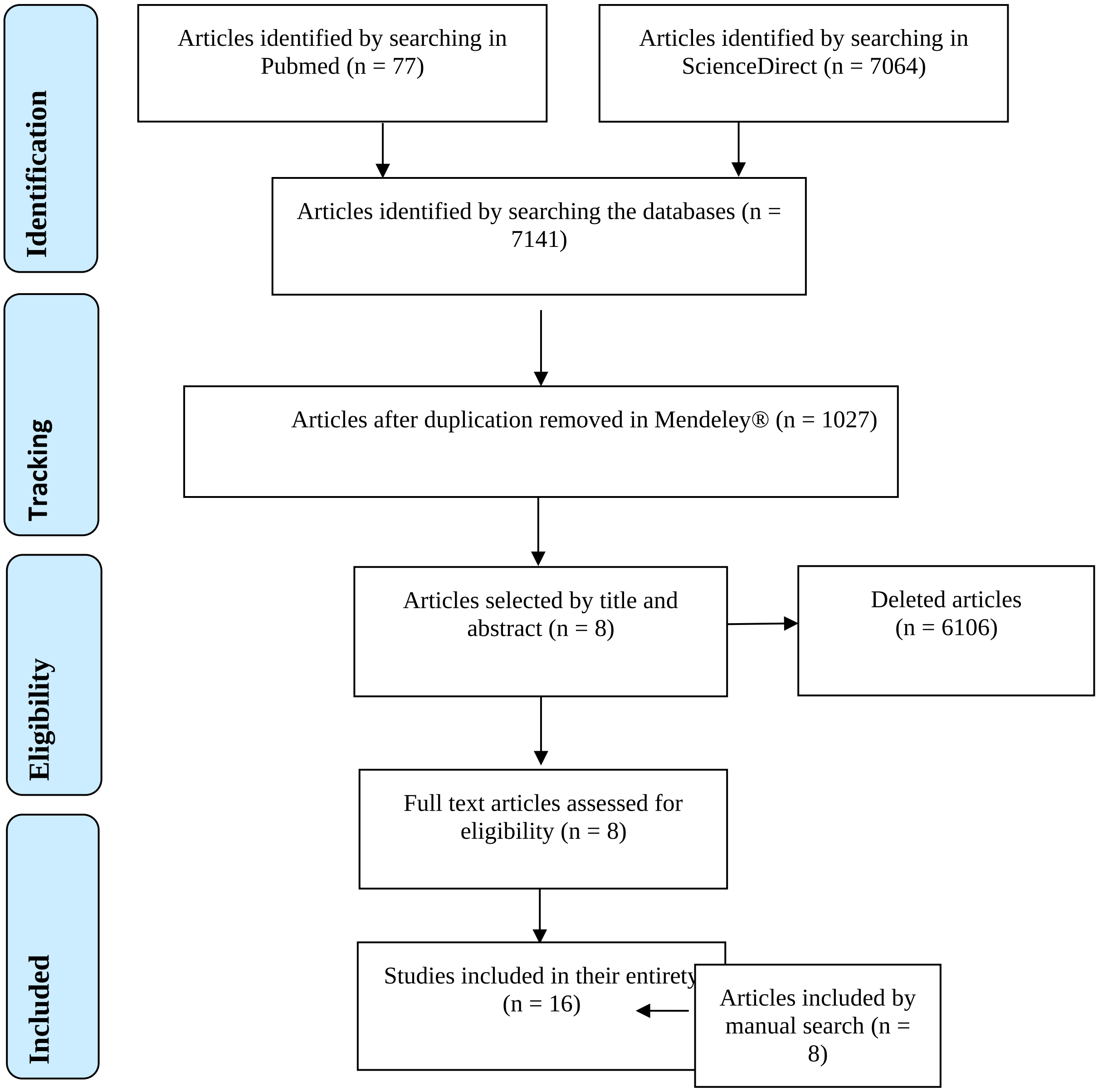

Figure 1. Flow diagram of the search strategy used in this study.

Table 1: Data extracted from selected articles.

Author (YEAR)	Type of Study/Methods	Purpose	Type of Clear Aligner	Chemical composition of the attachment	Main outcomes
Alrawas et al (2021)(19)	Randomized clinical trial	Evaluating the effect of a CAD/CAM nickel-titanium retainer on the stability of mandibular anterior teeth and periodontal health and to compare it with other retainers. Setting/Sample	1-mm, vacuum-formed removable retainer (VFR; Scheu Dental, Germany).	N/A	No statistical significance was found between the CAD/CAM retainer and other retainers regarding the clinical failure rate. Less plaque accumulation and gingival inflammation were observed in the CAD/CAM NiTi retainer group.
Barreda et al (2017)(13)	Randomized clinical trial Scanning electron microscopy analysis of molds obtained from the surface of the attachments by three independent investigators.	Evaluating surface wear of two resin composites over six months in (Filtek Z350 XT, 3M ESPE and Amelogen Plus TW, Ultradent Products Inc.)	Invisalign ™ (Align Technology, CA, USA) Chemical composition: Polyurethane from methylene diphenyl diisocyanate and 1,6-hexanedial, additives	Organic matrix: BisGMA, TEGDMA, BISEMA (27.5wt%); fillers: colloidal silica; zirconium silicate glass (72.5wt%), (Z350, 3M, USA) Organic matrix: BisGMA, (24wt%); fillers: colloidal silica; zirconium silicate glass (76wt%), (Amelogen Plus TW, Ultradent products Inc., USA)	Comparison of initial and final images showed that all samples underwent some degree of modification of the surface texture, but there was never total destruction of the attachment.

Chen et al (2021)(12)	*In vitro* Wear testing under 10000 cycles and immersed in water .	Assess the operation time, shear bond strength, placement accuracy and wear resistance of 3 resin-matrix composite materials that were used for orthodontic attachments.	Aligner manufacturer (Angelalign, China)	Organic matrix: BisGMA, TEGDMA, BISEMA (27.5wt%); fillers: colloidal silica; zirconium silicate glass (72.5wt%), (Z350™, 3M, USA) Organic matrix: EBADMA, BisphenolA-bis-(2-hydroxy-3-mehacryloxypropyl) ether, TEGDMA, 3-trimethoxysilylpropyl methacrylate (16.5wt%); fillers: colloidal silica (83.5wt%), (Sonicfill™, Kerr, USA)	Wear volume loss (mm^3): Traditional resin-matrix composite (Z350 XT™): 0.75 ±0.09 Flowable resin-matrix composite (Z350 XT™): 1.91 ±0.10 Traditional resin-matrix composite (Sonicfill): 0.59 ±0.07
D'Antò et al (2019)(11)	*In vitro* Comparison using 3D images between the processing modes for orthodontic attachments.	Evaluating the role of different resin composite materials in the correct reproduction of attachment shape and positioning.	Clear aligners (Airnivol S.r.l., Italy)	Flowable and traditional resin-matrix composite	The accuracy of attachment reproduction was similar when using the three different resin-matrix composites. Orthodontic resin composite showed more overflow when compared with a flowable resin composite.
Dasy et al (2015)(9)	*In vitro* Measurements of vertical displacement force during aligner removal	Evaluating the retention of four types of clear aligners on a dental arch with various attachments.	vacuum-formed retainers	N/A	Ellipsoid attachments had no significant influence on the force required for aligner tray removal and hence on aligner tray retention.

El-Huni et al (2019)(20)	Qualitative study using one-to-one semi-structured interviews.	Exploring factors influencing compliance in adolescents treated with a Twin-block appliance.	N/A	N/A	The study highlights the multifaceted perceptions of removable functional appliance wear, with compliance fluctuating over time and a range of bias.
Koottathape et al (2012)(18)	*In vitro* Wear measurement using CCD microscope	Investigate and compare two- and three-body wear of microfilled, micro-hybrid, and nano-hybrid resin composite resins.	N/A	Organic matrix: Bis-GMA, UDMA, TEGDMA, TEGDMA (32 wt%). Inorganic fillers: SiO_2 (20–70 nm). SiO_2 in prepolymerized matrix (<20 µm) (Durafil VS™, Heraeus Kulzer, Germany). Organic matrix: Bis-GMA, Bis-EMA, UDMA. Inorganic fillers: SiO_2, ZrO_2, particle size at 0.01–3.5 µm, average at 0.6 µm (Filtek Z250™, 3M ESPE, USA) Organic matrix: Bis-GMA,Bis-EMA, UDMA. Inorganic filelrs: silanated barium glass, silanated colloidal silica, silinated silica (0.1-15µm) (Clearfil AP-X™, Kuraray, Japan) Organic matrix: Bis-GMA, UDMA, Bis-EMA, TEGDMA. Inorganic fillers: Aggregated SiO_2/SrO_2 clusters (0.8–1.4 µm size) an non-agglomerated SiO_2 paricles (20 nm	Wear volume loss (mm^3): Durafil VSTM™: 0.6 Clearfill AP-X™: 0.5 Filtek Z250™: 0.6 Filtek Supreme XT™: 0.4 MI Flow™: 0.1 Venus Diamond™: 4.01

				size) (Filtek Supreme XT™, 3 M ESPE, USA. Organic matrix: UDMA, Bis-MEPP, DMA. Inorganic fillers: Sr-glass, lanthanoid fluoride, SiO_2 (average = 700 nm) (MI Flow™, GC Corpotation, Japan. Organic matrix: TCD-DI-HEA, UDMA. Inorganic fillers: Ba-Al-F-silicate glass < 20 µm SiO2 (5nm size) (Venus Diamond™, Heraeus Kulzer, Germany).	
Mantovani et al (2019)(14)	*In vitro* Analysis of the aligner tray fitting using a scanning electron microscope image	Evaluating the influence of 2 different types of resin-matrix composites used to build orthodontic attachments.	Invisalign™ (Align Technology, USA) Clear Aligner™ (Scheu-Dental, Germany) F22 (Sweden&Martina, Due Carrare, Italy)	Bulk fill resin-matrix composites	Invisalign, CA Clear Aligner and F22 have comparable performance in terms of fitting on anchorage attachments. Conventional bulk-fill resin-matrix composites provides a proper fitting on anchorage attachments.

Osiewicz et al (2015)(17)	*In vitro* Wear measurement against a standard stainless steel counterbody using the ACTA wear device.	Evaluating both two and three body wear between direct and indirect resin-matrix composites.	N/A	Organic matrix: Bis-GMA, UDMA, bis-EMA. Inorganic fillers: zirconia, silica (Filtek Z250, 3M ESPE, Germany) Organix matrix: UDMA, Bis-EMA. Inorganic fillers: borosilicate glass, pyrogenic silica (Sinfonya, 3M ESPE, Germany) Organic matrix: Bis-GMA, urethane dimethacrylate, decandiol dimethacrylate. Inorganic fillers: silica, ytterbium trifluoride, copolymer (Heliomolar, Ivoclar Vivadent, Liechtenstein) Organic matrix: Cycloaliphatic dimethacrylate, urethane dimethacrylates, decamethylenedimethacrylate copolymer. Inorganic fillers: highly dispersed silica particles (Adoro, Ivoclar Vivadent, Liechtenstein) Organic matrix: Bis-GMA, UDMA, decandiol dimethacrylate. Inorganic fillers: surface treated alumina, silanated glass ceramics (Estenia C&B, Kuraray Dental, Japan)	Wear depth (µm) Clearfil AP-X™: 1.5 ±0.3 Filtek Z250™ : 7.0 ±1.4 Estenia C&B™: 0.8 ±0.2 Heliomolar™: 9.6 ±3.1 Sinfony™: 3.0 ±1.2 Adoro™: 17.3 ±3.3

				Bis-GMA, TEGDMA, silanated barium glass filler, silanated silica filler, silanated colloidal silica, dl-camphorquinone (Clearfil APX, Kuraray Dental, Tokyo, Japan)	
Papadopoulou et al (2019)(7)	*In vitro* Optical Profilometry	Estimating possible changes in roughness and the mechanical properties of Invisalign™ trayss over one- and two-week of treatment.	Invisalign™ (Align Technology, USA]	N/A	Intra-oral aging has a detrimental effect on the roughness and mechanical properties of Invisalign™ trays The deterioration of the properties is not time dependent but has been integrated within the first week of clinical usage.
Souza et al (2016)(16)	*In vitro* Wear measurement using by two- and three-body wear testing.	Evaluating the abrasive and reciprocating sliding wear resistance of four commercial resin-matrix composites for dental restorations under conditions that can be found in the mouth.	N/A	Organic matrix: Bis-GMA, Bis-EMA UDMA, TEGDMA. Inorganic fillers: Barium glass; Colloidal sílica, (73wt%) (Grandio So™, Voco, Germany) Organic matrix: Bis-GMA TEGDMA. Inorganic fillers: Barium glass; Colloidal sílica (56wt%) (CERAM-XTM™, Dentsply, USA) Organic matrix: Bis-GMA TEGDMA, Barium glass. Inorganic	Wear volume loss (mm^3): Grandio SO™: 0.06 Ceram-XTM™: 0.04 Clearfil TM™: 0.03 Natural Elegances™ : 0.04

				fillers: colloidal sílica, (82wt%) (Clearfil™, Kuraray, Japan) Organic matrix: Bis-GMA, Barium glass. Inorganic fillers: colloidal sílica, (54wt%) (Natural elegances™, Henry Schein, USA)	
Storey et al (2018)(22)	Randomized clinical trial	Evaluating the periodontal health implications of upper and lower bonded retainers versus upper and lower vacuum-formed retainers over 12 months	The vacuum-formed retainers (Essix™ C+) were built using the same 'Essix™ machine' and cooled rapidly with Arctic spray (Ortho-Care™).	N/A	After 1-year, bonded retainers were associated with a high accumulation of plaque and calculus than vacuum-formed retainers and minimally worse gingival inflammation than vacuum-formed retainers.
Vardimon et al (2010)(23)	*In vivo* Measurements with 2 strain gauge rosettes bonded to each aligner on the buccal sides of the incisor and the premolar.	Analyzing the distribution of forces when using the aligner.	Invisalign™ (Align Technology, USA)	N/A	Attachment reinforcement should be considered in demanding anchorage requirements.
Yaosen, et al (2021)(24)	*In vivo* Retrospective study	Assess the incidence of attachment loss during orthodontic clear aligner therapy and to identify risk factors that may predict such event.	Invisalign™ (Align Technology, USA	N/A	The attachment loss rate in incisor/canine attachments was recorded at 7.54%, at 3.34% on premolar, and at 11.49% on molars.

DISCUSSION

Attachments for orthodontic clear aligners are composed of resin-matrix composite and therefore can be vulnerable to wear from micro-movements on force transmission as well as from movements caused by placement and removal of the clear aligner trays. In fact, the degree of friction and wear of resin-matrix composites varies depending on their chemical composition and microstructure since a high content, nano-scale size, and type of fillers can control the wear rate (13) (9) (18) (17) (16) (24) (15). Although some studies have not focused on the wear behavior of orthodontic aligners and corresponding attachments, results from a few selected studies validate the hypothesis of the current review study. Significant findings of the clear aligners, attachments, materials, and methods were evaluated as follow.

Clear aligners and attachments

Commercial clear aligner trays for orthodontic treatment can be composed of polyurethane from methylene diphenyl diisocyanate and 1,6-hexanedial (23). Nowadays, several dental companies have developed orthodontic clear aligner trays with different features. For instance, Invisalign™ (Align Technology, California) uses custom-made alignment trays with standard thickness throughout the treatment although Clear-Aligner (Scheu Dental, Germany) offers aligner trays in standard different thicknesses (0.5, 0.625, and 0.75 mm) for each treatment stage. Clear aligners can be produced by traditional manufacturing techniques, stereolithography, or CAD-CAM although the orthodontist should be aware on the types of materials and processing techniques for a adequate selection.

A previous study performed a comparison between the planned distalization in ClinCheck™ software (Invisalign, USA) and the clinical result and concluded that the software overestimates the clinical result (26). An average change from T0 to T8 was significantly higher in the software model with 3.00 when compared to the clinical model with 2.25, resulting in an accuracy of approximately 78%. Thus, the software models do not accurately reflect the patient's final occlusion immediately at the end of active treatment (26). That is particularly important concerning the orthodontist has less influence during active orthodontic treatment (4). However, a few studies have evaluated the precision and effectiveness of individual tooth movement or the concordance between ClinCheck™ and the final result from the orthodontist's perspective (4,7,8,10). From the clinical point of view, the major possible agreement among clinicians would be the evaluation of the initial situation associated with a digital representation as well as between the digitally-simulated tooth movements and the clinical result of the orthodontic treatment (25).

A major concern for the orthodontist is the precision of the tooth movement with the use of removable orthodontic aligners (5). In complex cases, clinicians have a major challenge due to issues such as anchoring requirements, control of the occlusal plane and vertical dimension, anterior torque, and inclination of the teeth in the extraction sites (6). Torque control and molar anchoring are key factors to achieve success in mechanics when retractions are required to correct anterior crowding (5).The introduction of a variety of auxiliary components for the treatment with orthodontic aligners has offered many advantages to the orthodontist, increasing the scope of mechanics (2). That allows the successfully address of the issues of the aligner concept. For instance, the incorporation of anchorage with orthodontic mini-implants provides a further direct and indirect support and control on predictable programmed tooth movements (6). On dental movement, orthodontic forces must be transmitted as close to the moment of the resistance of the tooth. The use of accessories increases the transmission of force during the movements of distalization and torque of incisors, revealing a higher moment in the direction of movement. That principle seems to be absent in the first and second generations of clear aligners.

Recently, clear aligners have evolved by developing accessories to produce moments of forces capable of transforming the center of rotation into the center of resistance. Thus, that is approaching Andrew's concept of having pre-adjusted accessories for specific teeth (2). Regarding the Invisalign™ treatment protocol, aligner for rotation speeds of up to 2 degrees while aligner for incisor torque speeds up to 1 degree and aligner for distalization speeds up to 0.25 (28). Optimized fittings are now designed to improve anterior tooth extrusions and canine rotations with aligner forces. On controlling tooth movement, orthodontic accessories designed by designed by Align Technology (USA) according to some principles such as horizontal ellipsoid accessory, horizontal gingival beveled accessory or automatically placed by the software (optimized rotation). The use of additional mechanisms allows to increasing the range of treatment with clear aligners (6). Also, different attachment shapes have been designed (CA Power Grip, Invisalign attachments) to improve retention and facilitate complex movements. For instance, an average force moment of 7.9 N.mm was reported with the use of power ridges and 6.7 N.mm with the use of attachment. Such state-of-the-art accessories are customized for the patient's unique dental anatomy as shown in Figure 2.

Figure 1: Orthodontic attachment composed of resin-matrix composite. Morphological aspects well-defined edges.

On distalization movement without attachment, initial average force in the direction of movement was recorded at 0.8 N while an initial average force was recorded at 1.1 N on attachment. Also, an intrusive vertical component of 0.7N was recorded with attachment while 0.5 N was recorded without the attachment (29). Another previous study reported that distalization of maxillary molars was the most effective movement, regardless of the use of an attachment (28). The average precision of molar distalization supported with an accessory was recorded at 88.4%. while the average precision for distalization of maxillary molars was recorded 86.9% Without the support of an attachment (28). Comparing the efficacy between ellipsoid attachments and chamfered attachments in aligner retention, an increase of 90% retention was recorded on the chamfered attachment while 23% retention was recorded on ellipsoid attachment (9). The alignment adjustment was improved with the use of resin-matrix composites, and a significantly proper fitting was achieved for the attachments built from bulk-fill resin composites ($p = 0.034$) (14).

Wear on attachments and corresponding orthodontic aligners

Resin-matrix composites are materials with versatile applications in dentistry including the production of orthodontic attachments for clear aligners. Resin-matrix composites are composed of a mixture of methacrylate-based monomers (i.e., Bis-GMA, Bis-EMA, TEGDMA, UDMA) to embedding silanized inorganic fillers such as colloidal silica, zirconium silicate, zirconia, barium silicate, or ytterbium fluoride particles. Other molecules are included for inducing light-irradiated polymerization (i.e., canforquinone and tertiary amine) and controlling optical properties. The content of inorganic fillers can reach up 90wt% of the resin-matrix composites that determine their physical properties such as viscosity, strength, hardness, elastic modulus, etc (12,13,15–18). The size of inorganic fillers in commercial resin-matrix composites ranged from nano-scale (20 up to 60 nm) towards micro-scale from 1 up to 10 µm (15-18) (Table 1). The type, size, and amount of filler particles used in resin-matrix composites can have a significant influence on the mechanical performance of the resin-matrix composites.

Figure 2: Orthodontic attachment composed of resin-matrix composite after wear processes.

Several in vitro studies have shown the wear of resin-matrix composites in conditions simulating clinical uses regarding loading, acidic environment, abrasive tooth pastes, friction, and antagonist contacting surface (12,13,15–18). Considering the use of orthodontic attachments, the placement and removal of the clear aligner induce friction and wear on both attachment and clear aligner surfaces. A previous study reported surface wear of two resin composites (Filtek Z350 XT^{TM} and Amelogen Plu TW^{TM},) against Invisalign^{TM} aligner trays over six months (13). Comparison of initial and final images showed that all samples underwent some degree of modification of the surface texture, but there was never total destruction of the attachment (13). However, one resin-matrix composites revealed a lower wear. Significant surface changes on the aligner tray surfaces were noted by scanning electron microscopy when compared before and after several cycles of use in contact with the surface of attachments (13). The differences in mechanical properties promote a higher wear on the clear aligner trays when compared to the attachment counterbody since the resin-matrix composites possess higher strength, hardness, and elastic modulus (15-18). In another study, the wear rate and volumetric changes in a flowable resin-matrix composite was higher when compared to two traditional resin-matrix composites (p = 0.386) (12). No significant differences was found between the volumetric changes in two traditional resin-matrix composites (p = 0.157) (12). Those differences were correlated with the lower amount of inorganic filler and low molecular mass monomers present in the tested flowable resin-matrix composite. Low molecular mass monomers are often used to provide greater flowability to the resin-matrix composite (12,13,15–18).

Results of a previous on the shape and volume of the attachments designed and manufacturing using three different compounds of different viscosity showed a significant differences on overflowing (11). In particular, a resin-matrix composite used in orthodontics (Bracepaste™ Medium Viscosity Adhesive, AO American, Canada), with a medium degree of viscosity, showed a higher tendency to overflow when compared to a traditional flowable resin composite (ENAMEL plus HRi®Flow HF, GDF GmbH, USA), with a low degree of viscosity (11). In fact, there are no current guidelines on the optimum physical properties of orthodontic attachment during therapy with a clear aligner trays. The fitting of the clear aligner can be changed mainly due to the chemical composition and properties of attachments since the thickness of the aligner is not changed during the period of use. The changes in volume and fitting of the orthodontic clear aligner and attachments negatively affect the efficiency of tooth movement (7,14,31).

CONCLUSIONS

Within the limitations of the selected studies, the following concluding remarks can be drawn as follow:

- Multi-directional forces generated during insertion and removal of orthodontic aligners can result in wear on both the aligner trays and the attachment surfaces;
- The contact area is altered or decreased due to wear, resulting in the magnitude change of forces onto the teeth in the planned direction. The misfit, loss of material, and release of toxic molecules in the oral cavity are the major issues from the wear process.
- The chemical composition of the resin composite can influence the wear of the attachment. Resin-matrix composites with a higher inorganic filler content can promote the wear on the aligner surface. Contrarily, the organic matrix is susceptible to the material loss and release of toxic molecules such as bisphenol A;
- Clinicians should be aware on the type, proportion, and properties of organic matrix and inorganic fillers in commercial resin-matrix composites and therefore a proper selection of materials may decrease the wear of the attachments and orthodontic aligners' surfaces;
- Further studies are required to determine the wear rate and change of volume of different resin-matrix composites used for orthodontic attachments in contact with different clear aligner trays.

REFERENCES

1. Malik OH, McMullin A, Waring DT. Invisible Orthodontics Part 1: Invisalign. dent Updat. 2013 Apr;40(3):203–15.

2. Hennessy J, Al-Awadhi EA. Clear aligners generations and orthodontic tooth

movement. J Orthod. 2016;43(1):68–76.

3. Choi NC, Park YC, Jo YM, Lee KJ. Combined use of miniscrews and clear appliances for the treatment of bialveolar protrusion without conventional brackets. Am J Orthod Dentofac Orthop [Internet]. 2009;135(5):671–81. Available from: http://dx.doi.org/10.1016/j.ajodo.2006.12.025

4. Krieger E, Seiferth J, Marinello I, Jung BA, Wriedt S, Jacobs C, et al. Invisalign® treatment in the anterior region: were the predicted tooth movements achieved? J Orofac Orthop. 2012 Sep;73(5):365–76.

5. Dai FF, Xu TM, Shu G. Comparison of achieved and predicted tooth movement of maxillary first molars and central incisors: First premolar extraction treatment with Invisalign. Angle Orthod. 2019 Sep;89(5):679–87.

6. Bowman SJ, Celenza F, Sparaga J, Papadopoulos MA, Ojima K, Lin JC-Y. Creative adjuncts for clear aligners, part 3: Extraction and interdisciplinary treatment. J Clin Orthod. 2015 Apr;49(4):249–62.

7. Papadopoulou AK, Cantele A, Polychronis G, Zinelis S, Eliades T. Changes in Roughness and Mechanical Properties of Invisalign(®) Appliances after One- and Two-Weeks Use. Mater (Basel, Switzerland). 2019 Jul;12(15).

8. Krieger E, Seiferth J, Marinello I, Jung BA, Wriedt S, Jacobs C, et al. Invisalign®-Behandlungen im Frontzahnbereich: Wurden die vorhergesagten Zahnbewegungen erreicht? J Orofac Orthop. 2012;73(5):365–76.

9. Dasy H, Dasy A, Asatrian G, Rózsa N, Lee HF, Kwak JH. Effects of variable attachment shapes and aligner material on aligner retention. Angle Orthod. 2015;85(6):934–40.

10. Brusveen EMG, Brudvik P, Bøe OE, Mavragani M. Apical root resorption of incisors after orthodontic treatment of impacted maxillary canines: A radiographic study. Am J Orthod Dentofac Orthop [Internet]. 2012;141(4):427–35. Available from: https://www.sciencedirect.com/science/article/pii/S0889540611012017

11. D'Antò V, Muraglie S, Castellano B, Candida E, Sfondrini MF, Scribante A, et al.

Influence of dental composite viscosity in attachment reproduction: An experimental in vitro study. Materials (Basel). 2019;12(23).

12. Chen W, Qian L, Qian Y, Zhang Z, Wen X. Comparative study of three composite materials in bonding attachments for clear aligners. Orthod Craniofac Res. 2021 Jan;00:1–8.

13. Barreda GJ, Dzierewianko EA, Muñoz KA, Piccoli GI. Surface wear of resin composites used for Invisalign® attachments. Acta Odontol Latinoam. 2017 Aug;30(2):90–5.

14. Mantovani E, Castroflorio E, Rossini G, Garino F, Cugliari G, Deregibus A, et al. Scanning electron microscopy analysis of aligner fitting on anchorage attachments. J Orofac Orthop. 2019;80(2):79–87.

15. Wimmer T, Huffmann AMS, Eichberger M, Schmidlin PR, Stawarczyk B. Two-body wear rate of PEEK, CAD/CAM resin composite and PMMA: Effect of specimen geometries, antagonist materials and test set-up configuration. Dent Mater [Internet]. 2016;32(6):e127–36. Available from: http://dx.doi.org/10.1016/j.dental.2016.03.005

16. Souza JCM, Bentes AC, Reis K, Gavinha S, Buciumeanu M, Henriques B, et al. Abrasive and sliding wear of resin composites for dental restorations. Tribol Int [Internet]. 2016;102:154–60. Available from: http://dx.doi.org/10.1016/j.triboint.2016.05.035

17. Osiewicz MA, Werner A, Pytko-Polonczyk J, Roeters FJM, Kleverlaan CJ. Contact- and contact-free wear between various resin composites. Dent Mater [Internet]. 2015;31(2):134–40. Available from: http://dx.doi.org/10.1016/j.dental.2014.11.007

18. Koottathape N, Takahashi H, Iwasaki N, Kanehira M, Finger WJ. Two- and three-body wear of composite resins. Dent Mater [Internet]. 2012;28(12):1261–70. Available from: http://dx.doi.org/10.1016/j.dental.2012.09.008

19. Alrawas MB, Kashoura Y, Tosun Ö, Öz U. Comparing the effects of CAD/CAM nickel-titanium lingual retainers on teeth stability and periodontal health with

conventional fixed and removable retainers: A randomized clinical trial. Orthod Craniofacial Res. 2021;24(2):241–50.

20. El-Huni A, Colonio Salazar FB, Sharma PK, Fleming PS. Understanding factors influencing compliance with removable functional appliances: A qualitative study. Am J Orthod Dentofac Orthop [Internet]. 2019;155(2):173–81. Available from: https://doi.org/10.1016/j.ajodo.2018.06.011

21. Flores-Mir C, Brandelli J, Pacheco-Pereira C. Patient satisfaction and quality of life status after 2 treatment modalities: Invisalign and conventional fixed appliances. Am J Orthod Dentofac Orthop [Internet]. 2018;154(5):639–44. Available from: https://doi.org/10.1016/j.ajodo.2018.01.013

22. Storey M, Forde K, Littlewood SJ, Scott P, Luther F, Kang J. Bonded versus vacuum-formed retainers: A randomized controlled trial. Part 2: Periodontal health outcomes after 12 months. Eur J Orthod. 2018;40(4):399–408.

23. Vardimon AD, Robbins D, Brosh T. In-vivo von Mises strains during Invisalign treatment. Am J Orthod Dentofac Orthop Off Publ Am Assoc Orthod its Const Soc Am Board Orthod. 2010 Oct;138(4):399–409.

24. Yaosen C, Mohamed AM, Jinbo W, Ziwei Z, Al-Balaa M, Yan Y. Risk Factors of Composite Attachment Loss in Orthodontic Patients during Orthodontic Clear Aligner Therapy: A Prospective Study. Biomed Res Int. 2021;2021:6620377.

25. Ravera S, Castroflorio T, Garino F, Daher S, Cugliari G, Deregibus A. Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study. Prog Orthod. 2016;17:12.

26. Izhar A, Singh G, Goyal V, Singh R, Gupta N, Pahuja P. Comparative Assessment of Clinical and Predicted Treatment Outcomes of Clear Aligner Treatment: An in Vivo Study. Turkish J Orthod. 2019;32(4):229–35.

27. Caruso S, Nota A, Ehsani S, Maddalone E, Ojima K, Tecco S. Impact of molar teeth distalization with clear aligners on occlusal vertical dimension: a retrospective study. BMC Oral Health. 2019 Aug;19(1):182.

28. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Treatment outcome and efficacy of an aligner technique--regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health. 2014 Jun;14:68.

29. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Forces and moments generated by removable thermoplastic aligners: Incisor torque, premolar derotation, and molar distalization. Am J Orthod Dentofac Orthop [Internet]. 2014;145(6):728–36. Available from: https://www.sciencedirect.com/science/article/pii/S0889540614003096

30. Eliades T, Papageorgiou SN, Ireland AJ. The use of attachments in aligner treatment: Analyzing the “innovation” of expanding the use of acid etching–mediated bonding of composites to enamel and its consequences. Am J Orthod Dentofac Orthop [Internet]. 2020;158(2):166–74. Available from: https://doi.org/10.1016/j.ajodo.2020.04.008

31. Rosti F, Sfondrini MF, Bressani D, Vitale MC, Gandini P, Scribante A. Digital Workflow for Indirect Bonding with 2D Lingual Brackets: A Case Report and Procedure Description. Vol. 2019, Case reports in dentistry. 2019. p. 6936049.