Original Research

Microleakage Evaluation of Glass Hybrid Restoration Following Usage of Papain-Based Gel and Ceramic Bur for Caries Removal: An In Vitro Study

Halah Abdulkareem A. Alkhawaja[1], Aseel Haidar M.J. Al Haidar[2]

[1]Department of Pedodontics and Preventive Dentistry, College of Dentistry, University of Baghdad, Iraq, [2]Assistant professor, Department of Pedodontics and Preventive Dentistry, College of Dentistry, University of Baghdad, Iraq

Abstract

Introduction: In the field of pediatric dentistry, an urge to adopt a more comfortable, minimally invasive, and stressless technique for caries removal became a must. Coronavirus disease-2019 outbreak necessitates a paradigm change in the global health care protocols, requiring alternative, nonaerosol generating approaches. This study aimed to measure and compare the influence of two methods of caries removal, namely, Brix3000 and CeraBur, on the microleakage of glass hybrid restorative material. **Materials and Methods:** Thirty human primary molar teeth with accessible occluso-gingival carious cavitation were randomly allocated into CeraBur and Brix3000 groups. After selective caries excavation, samples were restored with Equia Forte HT, thermocycled, dipped in thiazine dye, washed, and sectioned through the restoration center. Then microleakage was measured using a stereomicroscope (30× magnification) at both occlusal and gingival margins. **Results:** No statistically significant difference was found between the two methods of caries removal (CeraBur and Brix3000) at both occlusal ($P = 1.000$) and gingival margins ($P = 0.612$). **Conclusions:** Brix3000 caries removing gel did not negatively affect the microleakage of Equia Forte HT compared to the CeraBur and hence can be used alternatively to the conventional drilling methods.

Keywords: Brix3000, CeraBur, ceramic bur, chemomechanical caries removal, microleakage, papain gel

Introduction

The most commonly used treatment approach for dental caries is the conventional method of caries removal using rotary instruments. However, this method involves several complications and often induces fear and anxiety in patients, becoming an obstacle to achieving good treatment.[1,2]

In light of the new era of minimally invasive dentistry, new cutting burs made of ceramic were introduced with improved tactile sensation.[3] However, their use is still linked to rotary system issues, such as pulp overheating, the necessity for local anesthetic, and vibratory discomfort.[4]

The coronavirus disease-2019 pandemic forced a shift in global health care protocols. Aerosol-generating rotary instruments result in operator/patient cross infection. Hence, an alternative, less invasive, stressless, and nonaerosol producing approach is necessary.[5,6]

The chemomechanical caries removing (CM-CR) method seems to fulfill those requirements compared to the conventional drilling methods. CM-CR reinforces a favorable attitude toward dental procedures and has gained acceptance, especially from children and patients with dental anxiety and fear. The latest introduced CM-CR agent was BRIX3000, an enzymatic papain-based agent containing 3000 U/mg papain in 10% concentration, bioencapsulated via Encapsulating Buffer Emulsion technology, which gives the gel an ideal pH to immobilize the enzymes and release them when needed.[7,8]

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Address for correspondence: Halah A. A. Alkhawaja, Najaf, Iraq. E-mail: halaalkhawaja2020@gmail.com

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This study aimed to measure and compare the influence of two methods of caries removal: papain-based caries removal gel (Brix3000) versus the conventional rotary method (CeraBur) on the microleakage of glass hybrid restorative material (Equia Forte HT).

Materials and Methods

Simple randomization was adopted in this study by an independent person to randomly divide samples into two main groups according to the method of caries removal: CeraBur (control) and Brix3000 group using the "Random sequence Generator" tool (https://www.random.org/sequences).

Methodology

The Ethics Committee of Baghdad University/college of dentistry approved the study protocol.

Sample preparation

This study included 30 human primary molar teeth with accessible class II carious cavitation. Teeth were extracted as a part of an orthodontic treatment plan (serial extraction), over retention, and normal exfoliation. Samples were stored after proper debridement and cleaning in 0.1 thymol solution (M Dent, Bangkok, Thailand) until use.[9] During the collection process, teeth that exhibited cracks or malformation were excluded when examined with a dental loupe and transillumination.[10]

A selective caries excavation was conducted in this study, with caries-affected dentine being set as an excavation end point. Before carious dentin excavation, a fine enamel diamond bur (VERDENT, Lodz, Poland) was used to remove undermined and carious enamel.[11] In the CeraBur group, a conventional technique using a rotary slow speed handpiece (NSK, Saitama, Japan) with ceramic bur (CeraBur, Komet, Lemgo, Germany) was utilized to remove carious infected dentine selectively [supplementary figure 1],[12] whereas in the other group an enzymatic papain-based caries removing gel (Brix3000, Brix S.R.L., Carcarañá, Argentina) was employed, followed by hand excavation [supplementary figure 2].[13]

According to the manufacturers' instructions, Brix3000 was applied three consecutive times to the carious lesion, and each time lasted for 2 minutes to soften the carious infected dentin. Then a blunt spoon excavator was used to remove the softened mass in a pendulum movement.

Excavation end point

The completeness of caries removal was evaluated by visual and tactile criteria (hardness of dentine)[14] along with the ability of CeraBur to tactilely distinguish between the healthy and infected dentine[3] and the self-limiting property of Brix3000.[8] A single well-trained operator performed all the procedures.

Restoration procedures

Cavities were washed, dried, and conditioned by applying a 20% polyacrylic acid (Cavity conditioner, GC, Tokyo, Japan) for 10 seconds and then washed and moisture dried gently by air without desiccation. A glass hybrid restorative material (Equia Forte HT, GC, Tokyo, Japan) was dispensed in an automatic mixer for 10 seconds and injected into the cavity through a capsule applicator (SDI Limited, Bayswater, Australia). Then the restoration was adequately adapted, finished, and polished.

Microleakage determination

The samples were stored in distilled water at 37°C for 24 hours.[15] They were subjected to a thermocycling process for 500 cycles between cold and hot water baths 5°C to 55°C, respectively, with 30-second dwell time at each temperature.[9]

Then, the teeth were dipped in 2% thiazine dye, methylene blue (Zuhair lab, Baghdad, Iraq) for 24 hours at 37°C. Before dipping, the specimens were completely coated in two coats of nail varnish (MARKT MEKYACH®, China), except for the filled cavity and 1 mm beyond the edges.[16] The root apices and furcation area were sealed with flowable composite (Ivoclar Vivadent AG, Schaan, Liechtenstein) to avoid dye solution penetration.[17] Then samples were washed thoroughly and dried. Each tooth was sectioned longitudinally at the restoration center by slow-speed sectioning saw (XP Precision Sectioning Saw, Ted Pella, California, USA) from mesial to distal surface into two halves to prepare it for microscopic evaluation.[18]

After saw sectioning, microleakage represented by dye penetration was measured in millimeters (mm) by Optika Vision lite 2.1 software (OPTIKA, Ponteranica, Italy) using a stereomicroscope (KRÜSS, Hamburg, Germany) under (30×) magnification. Two trained examiners assessed the sections. The image was taken for each tooth section by a camera (OPTIKA, Ponteranica, Italy) mounted on the stereomicroscope. Then each tooth received four readings, two for each half/section at two sites, one at the occlusal margin (OM) and the other at the gingival margin (GM). The highest recorded value was used to represent the tooth at each site.[19]

Intra- and inter-examiner agreements were 99% ($P = 0.99$), determined by the intraclass correlation coefficient (ρ). The two examiners who performed data measurements and the statistician were blinded to the method of caries removal. The groups were only revealed at the end of the measuring and data analysis process.

Sample size

It was determined based on a pilot study conducted prior to the research using G power software (3.1.9.7) with 1.21 effect size, 80% power of the study, two-tailed test at 5% alpha error of probability. With two groups, a minimum of 13 samples for each group was rounded to 15 to account for dropout.

Statistical analysis

Data analyses were performed by independent *t* test, Mann–Whitney *U* test, and Wilcoxon test using R 4.2.0 (R Foundation for Statistical Computing, Vienna, Austria). Shapiro–Wilk test was used for the assessment of normality.

Results

Mann–Whitney *U* test showed a nonsignificant difference for OM microleakage between groups Brix3000 and CeraBur ($P = 1.000$) [Figure 1]. Also, the independent *t* test revealed a nonsignificant difference for GM microleakage between groups Brix3000 and CeraBur ($P = 0.612$) [Figure 1] (supplementary tables 1 and 2).[20,21] Wilcoxon test showed significant differences between microleakage of GM and OM for groups Brix3000 ($P < 0.01$) and CeraBur ($P < 0.01$) [Figure 1] (supplementary table 3 and Figure 3).[22,23]

Discussion

The conventional drilling method for removing caries unnecessarily removes healthy or potentially mineralizable caries-affected dentin.[24]

CM-CR method selectively removes carious infected dentine, avoids unnecessary removal of sound dentine, minimizes inconvenience associated with local anesthetic administration, and is noise-free. These factors can help emphasize a child's positive behavior, which results in improved cooperation.[7,25]

As the success of a restoration is highly reliant on a good marginal seal, microleakage evaluation is regarded as a valid tool for assessing different methods for caries removal.[26]

In 2019, the newest Equia Forte HT material (GC, Tokyo, Japan) was launched into the market, composed of a hybrid glass-ionomer system with a greater viscosity than the earlier generation Equia Forte Fil. Glass hybrid materials based on GIC technology had been developed by adding glass particles of varying sizes to the usual filler, such as highly reactive tiny particles. This characteristic boosts reactivity and greatly improves the material's mechanical capabilities, making it appropriate for long-lasting fillings.[27]

In this study, both caries removing methods showed some microleakage values in Equia Forte HT restoration at both the OM and GM; however, no statistically significant differences were found between them at the OM and GM. This might be owing to the proximity of the excavation end point of CeraBur and Brix3000 (both being at the affected dentin). These data agreed with those of Kwak *et al.*,[28] regarding the Brix3000 group, and Fathy *et al.*,[26] regarding the Cerabur group. In contrast, they were inconsistent with the findings of Ludeña and Bravo,[29] regarding the Brix3000 group, this may be related to the fact that carbide burs were not as conservative as the CeraBur and did not provide tactile confirmation. Also, the study used composite restoration rather than glass-based restoration.

According to manufacturers (Komet, 2015), the CeraBur permits controlled and tactile excavation in a way that when it leaves the soft, carious dentin, the operator can feel it. This property provides high excavation capabilities on softened carious dentin while preserving as much sound tooth structure as possible.[30]

Brix3000 has a self-limiting property. When the gel reaches the healthy dentin, two mechanisms neutralize its activity: physiologically and microphysiologically by the activity of the α1-antitrypsin antiprotease enzyme and the unrestrained collagen fibers. So its mechanism ceases once it reaches the healthy dentine,[8] which might explain the result of this study.

When it comes to margin site location, this study showed a high statistically significant difference existed in the microleakage values when comparing the OM and GM within the CeraBur group ($P < 0.01$) and the Brix3000 group ($P < 0.01$), with more microleakage values associated with the GM tooth-restoration interface than in the occlusal interface in each group.

Thus, the results of this study suggested that neither method (Brix 3000 and CeraBur) adversely affected the microleakage of Equia Forte HT restoration. Although further clinical

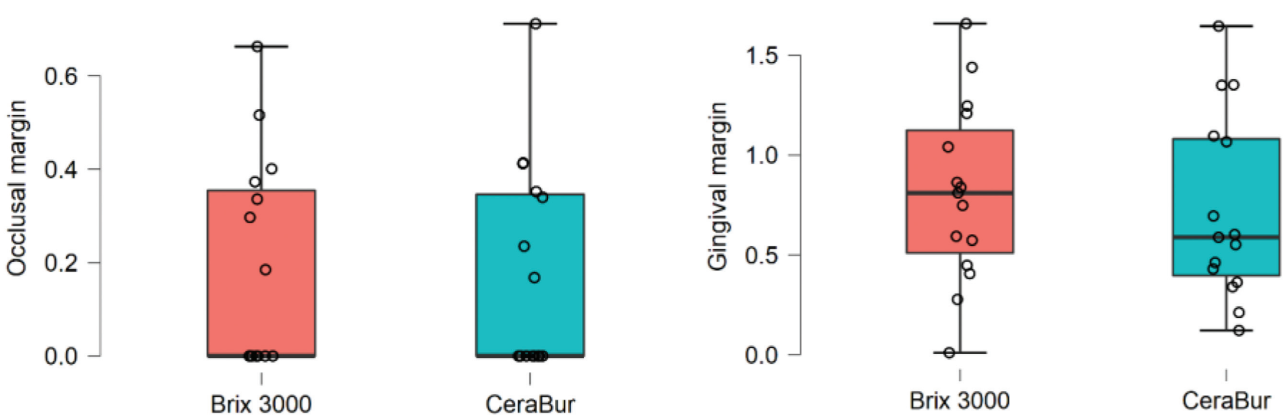

Figure 1: Box and whisker plots showed results of the microleakage in millimeters

studies should back up the current laboratory study result, it might provide some information for clinicians who elect to incorporate these agents into clinical work.

Limitation

More studies using other restorative materials and comparing other caries removing agents and methods are required to establish the effect of the papain Brix 3000 gel on marginal sealing (microleakage). Also, in vivo confirmation of the result is required due to different variables related to the oral environment.

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Conflicts of interest

There are no conflicts of interest.

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Original Research

Evaluation of Friction and Surface Characteristics of Two Types of Self-Ligating Bracket Gate: An In Vitro Study

Hussein A. Kanbar[1], Dina H. Obaid[1], Ali I. Ibrahim[1,2]

[1]Department of Orthodontics, College of Dentistry, University of Baghdad, Baghdad, Iraq, [2]Centre for Oral, Clinical and Translational Sciences, Faculty of Dentistry, Oral & Craniofacial Sciences, King's College London, London, UK

Abstract

Introduction: Frictional forces generation during orthodontic treatment with fixed appliances impedes appropriate tooth movement; hence, research is ongoing to explore "frictionless" techniques. This in vitro study compares Damon Q and Pactive self-ligating metallic brackets in terms of friction and surface characteristics of the bracket gates when using CuNiTi archwires during leveling and alignment stage and examines the effects of aging conditions on frictional force generation. **Methods:** A total of 108 metallic self-ligating brackets (Damon Q and Pactive) were investigated for frictional resistance with round 0.014″ and rectangular 0.014″∗0.025″ CuNiTi archwires post exposure to water storage and acidic attack aging conditions. The bracket gate surface characteristics were evaluated using scanning electron microscope (SEM). **Results:** There was no statistically significant difference ($P > 0.05$) in friction generation between the two bracket systems when coupled with 0.014″ CuNiTi archwire, but the Pactive brackets yielded significantly higher frictional forces ($P < 0.05$) when coupled with 0.014″∗0.025″ archwire. The SEM findings revealed nonsignificant differences ($P > 0.05$) between the surface characteristics of the bracket gates. **Conclusions:** Damon Q brackets generate low frictional forces, suggesting better performance than Pactive brackets during the first phase of orthodontic treatment. A modified scoring system was developed for an objective description of bracket surface characteristics.

Keywords: Bracket gate, CuNiTi archwire, friction, self-ligating brackets

Introduction

The success of orthodontic treatment using straight wire appliances depends on the ability of the archwire to slide through the brackets and tubes at various stages of treatment.[1] The main problem encountered to achieve proper orthodontic tooth movement is the generation of frictional forces, which are the forces that oppose movement between two surfaces[2] (supplementary text 1).[3]

Materials and Methods

Materials

Two types of metallic self-ligating brackets of upper right central incisor with a slot size 0.022∗0.028″ (standard torque prescription for the Damon Q brackets and Roth prescription for the Pactive brackets) were investigated: 56 Damon Q (Ormco Corporation, USA) and 56 Pactive brackets (IOS company, USA), coupled with two gauges of CuNiTi archwires (round 0.014″ and rectangular 0.014∗0.025″). The straight ends of the archwires were cut and used for the friction test: 36 pieces of 0.014″ and 36 pieces of 0.014∗0.025″ CuNiTi archwires (Damon Q, Ormco Corporation, Orange, CA, USA).

Methodology

Preparation of the experimental blocks for testing the friction

Three brackets from each system were fixed on a plastic block using a cyanoacrylate adhesive (Soma Kimya Co., Turkey).

Address for correspondence: Ali I. Ibrahim, Baghdad, Iraq.
E-mail: ali.ibrahim@gktalumni.net

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Each block had three squares, with the central one positioned 2 mm higher than the other squares; the distance between the midpoints of the squares was 11 mm to mimic a segment of the dental arch that is unaligned,[4] as shown in (supplementary figure 1A).[5] A straight stainless steel wire jig of 0.021∗0.025″ gauge was used to align the brackets on the plastic blocks (supplementary figure 1B)[5] to eliminate the torque and the tip (factors affecting friction force).

Study design

The study was approved by the Research Ethics Committee of the College of Dentistry, University of Baghdad (Reference number: 588/588422).

Data analysts and biostatisticians were blinded toward the different types of brackets study models used. A simple, single-blinded, randomized allocation was employed for 36 study models with a minimum sample of nine models per subgroup, which was required to verify a significant difference in frictional forces between subgroups calculated based on a previous study[6] with an effect size of 0.35 and 80% power, two-tailed test at 5% level of significance using G-power version 3.1.9.7. The friction was assessed for four subgroups; each was subjected to two bracket/archwire combinations, as demonstrated in (supplementary figure 2).[7]

Sample exposure to aging conditions

Samples were subjected to two aging conditions: acid challenge and water storage. For the acid challenge, the samples were exposed to an acidic solution that was prepared daily by gradually adding 3.5 mL of 1 molar hydrochloric acid solution (Thomas Baker Co., India) to 500 ml of distilled water until the acidity was set on a pH value of 2.5, using a protocol of three sessions per day, 5 minutes each, with equal intervals between sessions (2 hours) for 30 days. To simulate the wet oral environment, samples were placed in distilled water at 37°C (pH = 6) for the rest of the day.[8] For the water storage, the samples were immersed in distilled water and stored inside the incubator at 37°C for 30 days; the distilled water was replenished daily.[8]

The friction test

Friction was assessed using the Instron (H50KT Tinius Olsen, England) testing machine with a load cell of 10 N. The model was held by the machine's lower part (the fixed part), while the upper part (the load cell) clamped the free end of the wire[9] (supplementary figure 3).[10] Following the data entry, each wire was pulled through the bracket slot over a distance of 5 mm at a speed of 5 mm/minute[2] until a 5 mm length of the wire was entirely pulled through the bracket. Each of the four subgroups involved nine models; each model was tested by pulling the round 0.014″ followed by the rectangular 0.014″∗0.025″ CuNiTi archwires. Meanwhile, a plastic syringe (china) was used to drip distilled water on the bracket/wire combination during the friction test. Only 3 mL/min of distilled water was dripped in each test for standardization purposes.[11] Frictional forces were displayed on the computer screen of the testing machine (QMat 4.53 T series software, England) and both the static and kinetic frictions were calculated.

Assessment of surface characteristics of bracket gates

The inner gate surfaces of 18 randomly selected brackets, with three "as-received from the manufacturer" brackets from both companies and three brackets of each artificial aging subgroup (post friction test) were analyzed with a scanning electron microscope (SEM) (Inspect F 50, Holland) at four magnifications: 150 ×, 300 ×, 5000 ×, and 10,000 ×. The images obtained were examined using a scale for quantitative classification described by Agarwal *et al*.,[12] but were modified in this study for a more objective description of surface characteristics, as shown below:

Score 0: Smooth surface (flat surface with no pits, no scratches, and no surface irregularities)

Score 1: Relatively smooth surface (flat surface with dispersing pits or mild surface irregularities)

Score 2: Relatively rough surface (when the surface has pits with scratches or grooves)

Score 3: Rough surface (the surface has pits, scratches/ grooves, and marked surface irregularities)

Two independent orthodontists scored the SEM images, and the outcomes were examined with the kappa interrater test. The percentage of agreement was 90%, which means almost perfect agreement.

Statistical analysis

The statistical analysis was conducted using the SPSS 23 statistical package of social sciences (SPSS Inc., Chicago, IL, USA) at a level of significance of $P < 0.05$. A parametric test (two samples independent t test) was used for frictional force analysis, while a nonparametric test (Mann–Whitney U test) was utilized to examine the difference in bracket gate surface scores.

Results

Normally distributed data were found according to the Shapiro–Wilk test; hence, parametric tests were used as follows.

Descriptive statistics

The descriptive statistics (mean, standard deviation, and minimum and maximum values) of the frictional force, measured in grams (g), of each subgroup are shown in (supplementary figure 4).[13] For both types of wires, the mean values of the frictional forces were higher with the Pactive brackets than with Damon brackets post both aging conditions (acid attack and water storage). Moreover, in two types of brackets, the acid challenge yielded an elevation in the frictional forces generated when these brackets were coupled with either wire type (round 0.014″ or rectangular 0.014∗0.025″ CuNiTi) (supplementary figure 4).[13]

Inferential statistics

Comparison between the two bracket systems

Independent samples *t* test showed a statistically insignificant difference between the mean values of both static and kinetic frictional forces of the two bracket systems when these brackets were coupled with the round CuNiTi wires in both aging conditions (water storage and acid challenge). However, there was a statistically significant difference between the mean values of the frictional forces (static and kinetic) of Damon Q and Pactive brackets when coupled with the rectangular CuNiTi wires in both aging conditions, as the Pactive brackets yielded significantly higher mean values of the frictional forces (supplementary figure 5).[14]

Comparison between the two aging conditions within the same bracket type

For the Damon brackets, the Independent samples *t* test revealed significantly higher mean values post brackets exposure to acid challenge than water when coupled with round wires, but there was no statistically significant difference when coupled with the rectangular archwires (supplementary figure 6).[15]

For the Pactive brackets, both archwire types yielded higher mean values of the kinetic frictional forces following exposure to acid challenge than water storage, but there was a statistically nonsignificant difference between the effects of acid and water storage on the static frictional forces (supplementary figure 6).[15]

SEM findings for the assessment of surface characteristics of the bracket gates

The SEM images were assessed according to the modified scoring system developed in this study. The "as received from the manufacturer" and "post-aging" Pactive brackets consistently yielded rougher surfaces than Damon Q brackets by recording higher scores (more pits, grooves/scratches, and surface irregularities) as shown in (supplementary figures 7, 8, and 9)[16–18] respectively. However, a statistically nonsignificant difference was revealed by the Mann–Whitney *U* test between the two bracket systems' surface characteristics of the bracket gates (supplementary figure 10).[19]

Discussion

Comparison of frictional forces between the two bracket types

Results showed no statistically significant difference in static or kinetic friction between the brackets under both aging conditions when coupled with round CuNiTi archwire in contrast to a statistically significant difference when using the rectangular archwire as the Pactive brackets produced significantly higher friction and this can be attributed to their flexible clip versus the sliding clip design of Damon brackets; as with the smaller round archwire, the clip acts passively, yet with the larger rectangular wire, the clip of the Pactive system encounters deflections yielding higher friction. This finding agreed with the results reported by Phaphriya *et al*.[20] Additionally, the Pactive bracket has a wider slot mesiodistally, which might increase the area of surface contact, hence exacerbating the friction.[21]

The available methods for evaluating metal bracket surface characteristics are relatively few, subjective, and lack a thorough description of the surface changes induced by orthodontic archwires.[12] Therefore, a modified scoring system was developed in the current study premised on a thorough evaluation of the surface changes as seen by the SEM images. The "as received from the manufacturer" and "post-aging" Pactive brackets demonstrated relatively higher scores with more pits, grooves/scratches, and surface irregularities on the bracket gate surface than Damon Q brackets. This finding can be attributed to the accuracy of the brackets manufacturing process, such as bracket milling or electro-polishing procedures that might initially leave surface defects. Moreover, acidic attacks could have exacerbated the corrosion, pitting, and grooving of these surfaces, a finding that has been confirmed previously.[22] However, pertaining to the bracket gate surface characteristics, statistically nonsignificant differences were found between the bracket systems, which may be caused by the bracket sample size that is small and used for SEM analysis ($N=3$ per each artificial aging subgroup). According to the abovementioned findings, the null hypothesis regarding friction generation is rejected, while there is insufficient evidence to reject the null hypothesis regarding the bracket gate surface characteristics.

Comparison between the effects of the two aging conditions on the same bracket system

With either type of brackets, exposure of brackets to acid challenge resulted in significantly higher frictional force mean values than exposure to water storage. This may be attributed to the corrosive effect of the hydrochloric acid solution on the bracket gate surface that can lead to metal ions release, causing many surface defects, a finding that has been reported previously.[22] On the other hand, these surface defects might have been induced by bracket milling, pickling, or electro-polishing processes and may accelerate the corrosion in the presence of acidic attacks, as mentioned by previous studies.[23] Thus, the null hypothesis assumed in the current study is rejected, as there were significant differences between the effects of the two aging conditions on the same bracket system.

Limitations of this study

The outcomes are based on in vitro models using limited numbers of brackets rather than full-arch models which may produce imprecision in data (supplementary text 1).[3]

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Conflicts of interest

There are no conflicts of interest.

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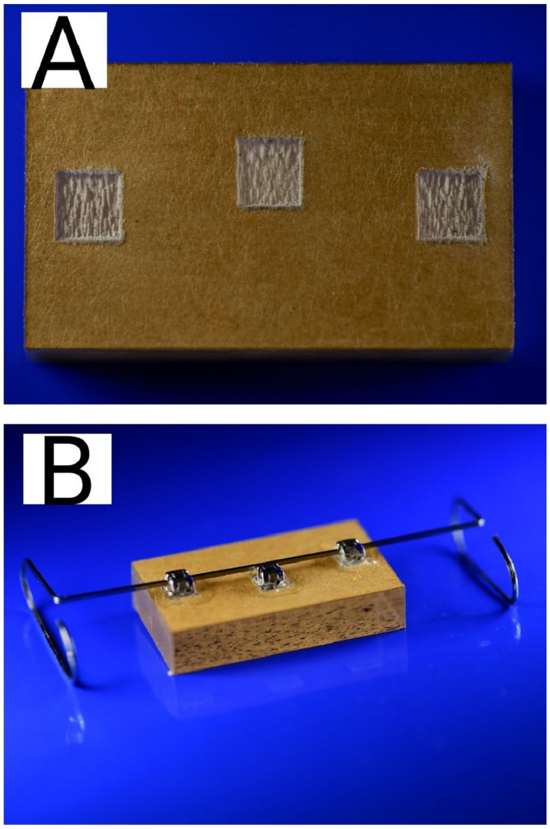
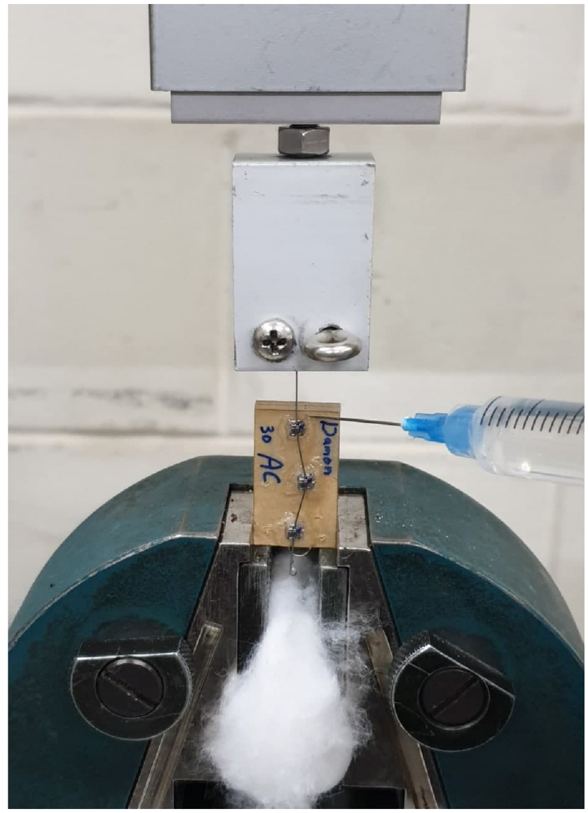
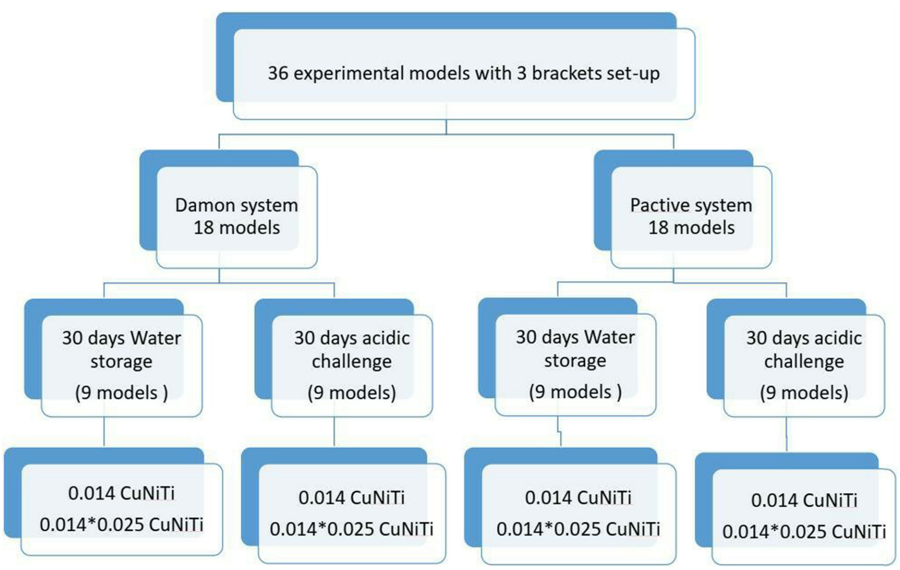


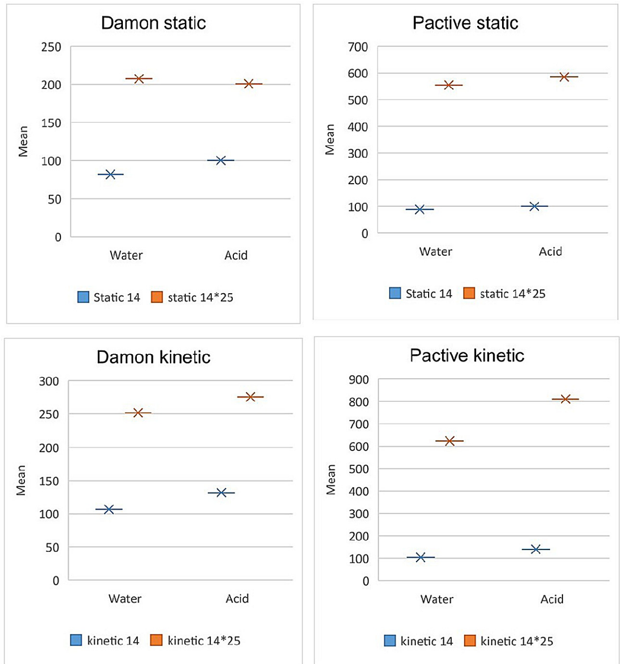
Supplementary Figure 1: A, an experimental block with 3 squares, setting the central one 2 mm higher than the others. B, aligning the brackets on the plastic block using a straight stainless steel wire of 0.021*0.025″ gauge.



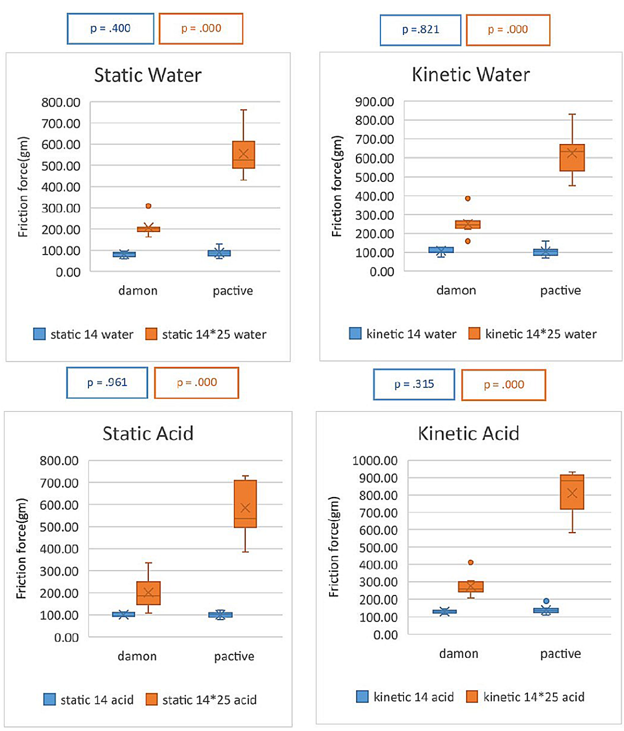
Supplementary Figure 3: friction test using the Instron machine, showing dripping of distilled water from a plastic syringe during the test.



Supplementary Figure 2: A schematic representation of the grouping of samples.

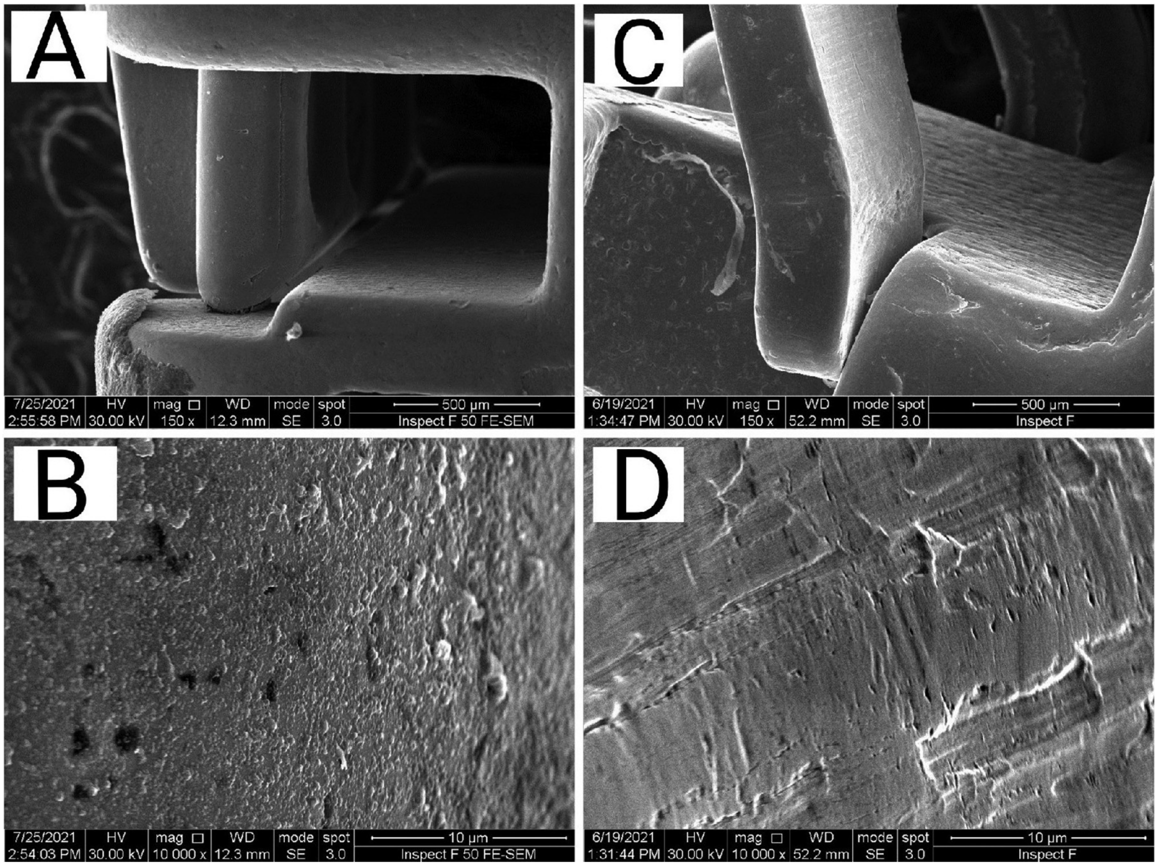


Supplementary Figure 4: Descriptive statistics of the static and kinetic frictional forces (g) of 4 subgroups. Pactive brackets demonstrated higher mean values than Damon brackets post both ageing conditions.

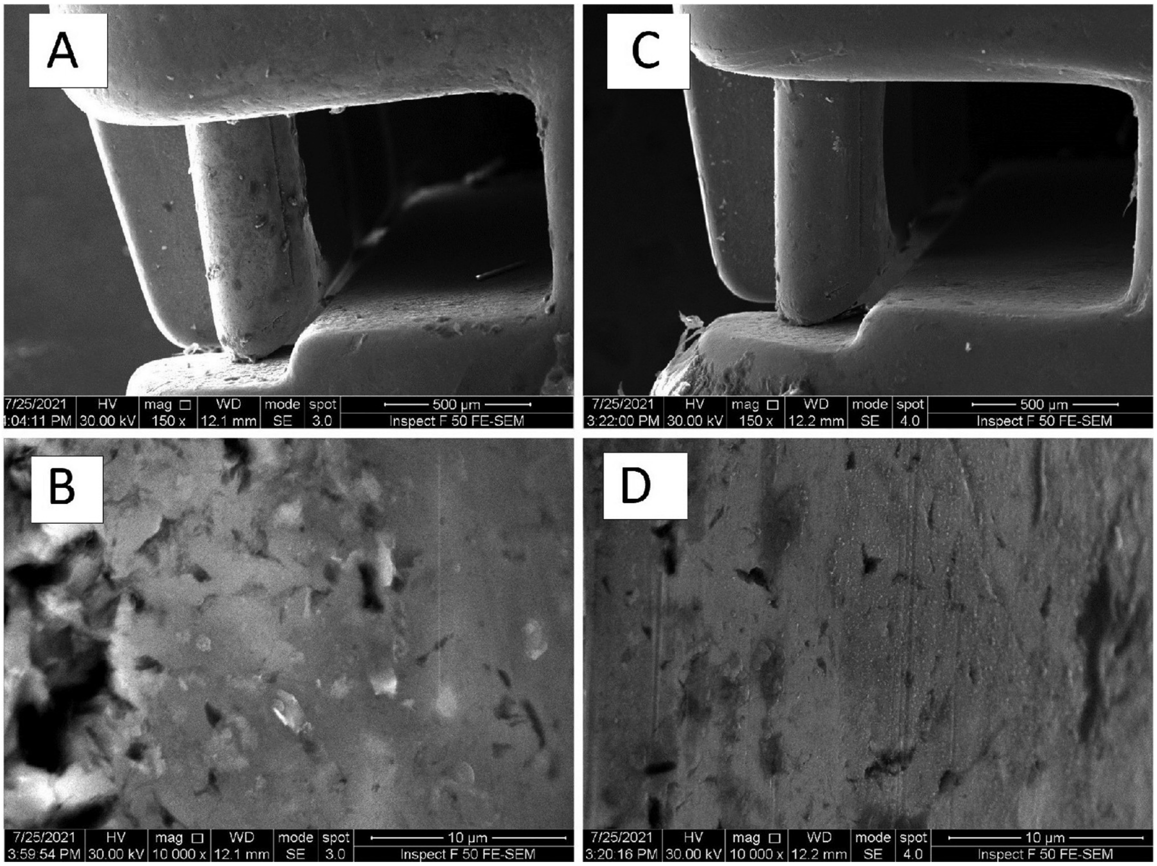


Supplementary Figure 5: Independent t-test for the comparison of frictional forces between the two bracket systems showing non-significant differences when using round CuNiTi wires, while Pactive system yielded significantly higher frictional forces than Damon system when coupled with the rectangular CuNiTi wires.

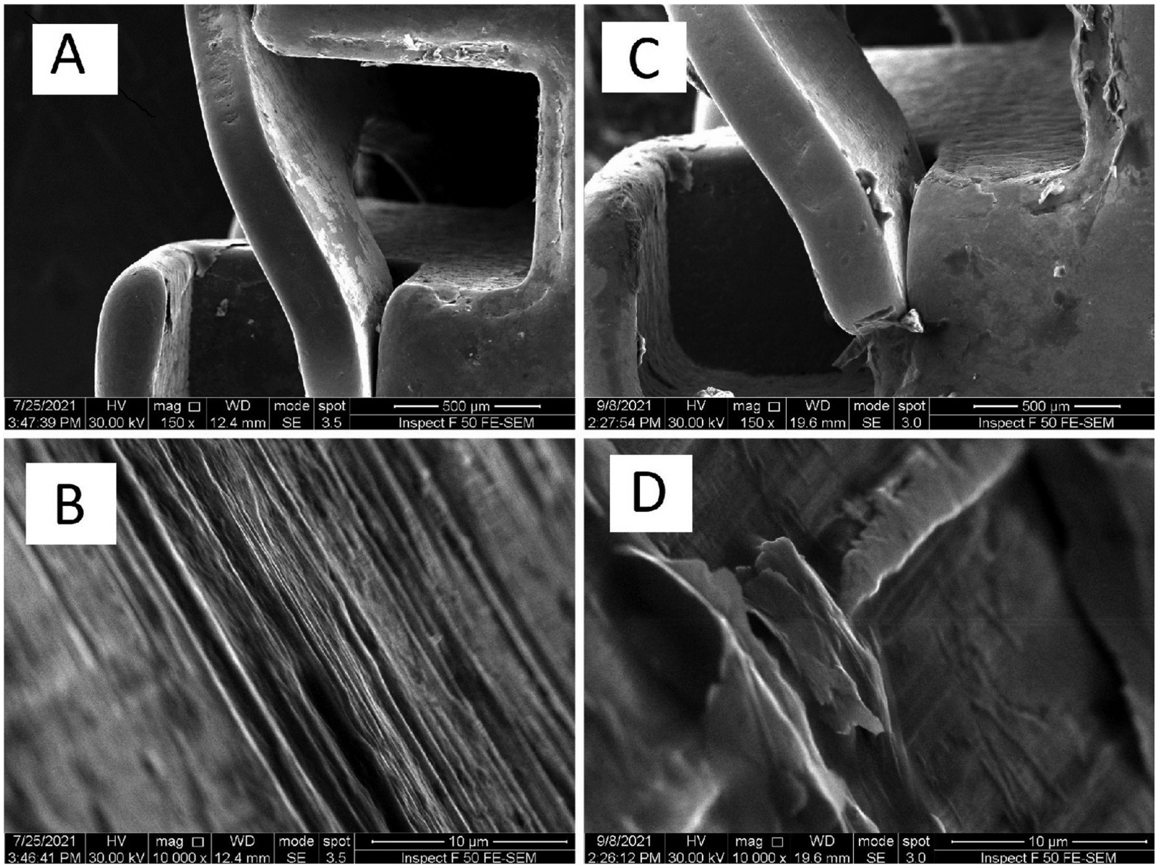
Supplementary Figure 6: Independent t-test for comparing the effect of two ageing conditions on frictional forces using Damon or Pactive brackets with two wire gauges. Regarding Damon brackets, the acid challenge elicited significantly higher static and kinetic frictional forces than water storage when these brackets coupled with round CuNiTi wires. For Pactive brackets, exposure to the acidic attack resulted in significantly higher kinetic frictional forces than water storage, with both wire gauges.



Supplementary Figure 7: SEM images of bracket gates before exposure to ageing. A, gate of Damon bracket showing the clip system. B, Damon bracket gate at 10000× magnification depicting score 1, which indicates a relatively flat smooth surface with disperse pits and mild surface irregularities. C, clip design of Pactive bracket gate. D, Pactive bracket gate at 10000× magnification eliciting score 2, which identifies a relatively rough surface with pits and scratches.

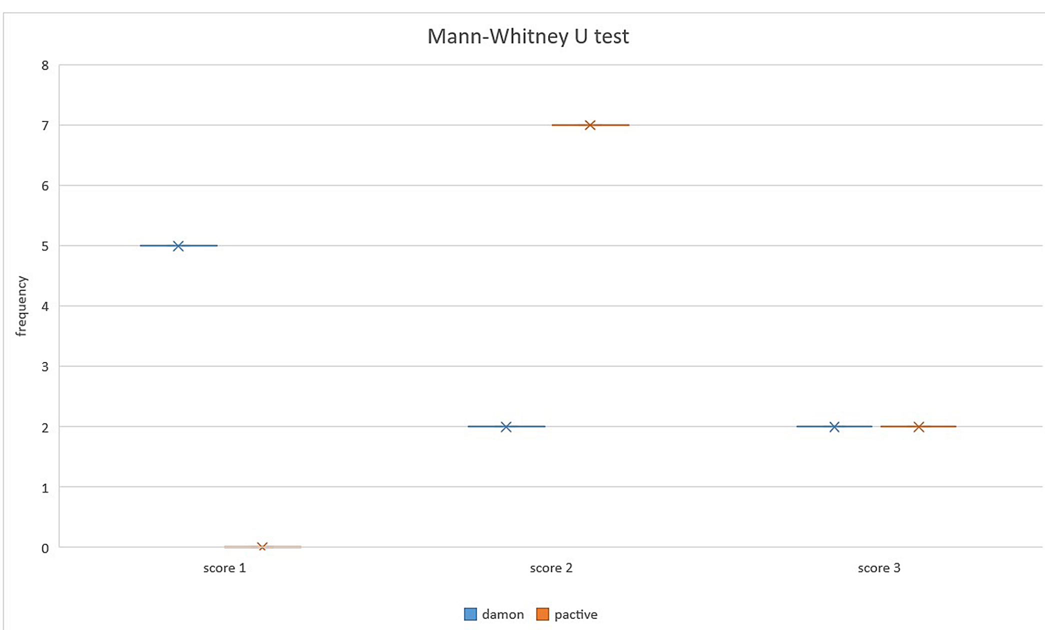


Supplementary Figure 8: SEM images of Damon brackets gates post exposure to ageing conditions; A: Damon bracket gate following water storage, B: at a higher magnification (10000×) the gate surface shows a relatively flat smooth surface with disperse pits and mild surface irregularities (score 1) after water storage, C: Damon bracket gate after acid challenge, D: at a higher magnification (10000×) the gate surface depicts a relatively rough surface with pits and grooves (score 2) after acid challenge.



Supplementary Figure 9: SEM images of Pactive brackets gates post exposure to ageing conditions; A: Pactive bracket gate after water storage, B: at a higher magnification (10000×) the gate surface demonstrates score 2 after water storage, C: Pactive bracket gate after acid challenge, D: at a higher magnification (10000×) the gate surface depicts a rough surface with pits, scratches/grooves and marked surface irregularities (score 3) after acid challenge.

P= 0.136



Supplementary Figure 10: Mann-Whitney U test for comparing the surface characteristics of Damon and Pactive brackets (N = 9 for each bracket type), showing non-significant differences between the frequencies of bracket gate smoothness/roughness scores despite higher frequencies of smoother Damon bracket gates.