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Research article

Effect of different surface conditioning methods and low pH solutions on the shear bond strength of orthodontic brackets to newly introduced CAD/CAM materials

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ABSTRACT

Aim: To evaluate the shear bond strength (SBS) of ceramic and metallic orthodontic brackets bonded to lithium disilicate ceramics or hybrid ceramics and subjected to different surface conditioning treatments.
Materials and methods: In total, 300 specimens were fabricated from GC LiSi (lithium disilicate) and GC Cerasmart (hybrid) ceramic blocks. The specimens were divided into four groups according to the following surface treatments: hydrofluoric acid (HF); sandblasting with 50 µm aluminum oxide; Monobond Etch and Prime; and erbium-doped yttrium aluminum garnet (Er-YAG) laser. Metal (Victory Series) and ceramic (Clarity) brackets were bonded using an orthodontic adhesive resin (Transbond XT; 3M Unitek, CA, USA). The specimens were then stored in three different mediums (artificial saliva, mouth rinse, and gastric juice) and thermocycled. An SBS test was performed after 1 week. The surface morphology was examined after the conditioning treatments using a scanning electron microscope. Data were analyzed using analysis of variance, *t*-test, and Duncan test.
Results: The SBS data revealed that the type of computer-aided design/computer-aided manufacturing (CAD/CAM) block and surface conditioning method significantly affected the SBS. The highest SBS was recorded (10.112 MPa) for the HF-treated hybrid ceramic blocks stored in the saliva medium, while the lowest SBS (1.862 MPa) was reported for the Er-YAG laser-treated lithium disilicate ceramic blocks stored in the gastric juice medium. GC Cerasmart exhibited better bond strength than that of GC LiSi; however, no significant difference was observed between the ceramic and metal brackets.
Conclusion: The CAD/CAM material, surface conditioning method, and medium affect the SBS.

1. Introduction

Recently, the demand for orthodontic treatment in adult patients has been increasing [1–3]. As these patients usually have ceramic restorations, dentists may have difficulty achieving adequate bonding between the brackets and these restorations [4,5]. Bracket failures have been reported to significantly prolong the treatment time; therefore, it is important to determine the most appropriate surface treatment for bonding [6–8].

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A bond strength of 6–8 MPa is clinically necessary for an ideal bond between the brackets and ceramic restorations [9]. Therefore, appropriate surface conditioning is crucial for creating micromechanical and chemical retention of the bonding brackets [10]. Additionally, proper treatment protocols prevent accidental bracket loss and damage to the surface after bracket removal [11,12].

Although ceramics preferred for crown and laminate veneer restorations have a high fracture resistance, they can cause wear in the opposing arch [13]. Furthermore, their production processes are lengthy because they need to undergo sintering to achieve their final mechanical properties [14]. To eliminate the sintering process in ceramic blocks, fully sintered blocks (GC LiSi) have been introduced in the market [15]. To overcome some of the negative features of ceramic blocks, hybrid blocks have been developed that combine the advantages of ceramics and resin polymers, which can be milled to their final form, thus reducing the chairside time [16,18].

Patients with esthetic restorative materials on their teeth also demand esthetic orthodontic systems, such as ceramic brackets [17,19]. To bond the ceramic restorations and ceramic brackets, a surface treatment is necessary to ensure adhesion between the ceramic surfaces that does not cause any damage when the brackets are removed [12].

As ceramics are chemically inert materials, a chemical or mechanical surface treatment of the ceramic restoration is necessary to establish adhesive bonding with the bracket [19,20]. Chemical methods for conditioning include hydrofluoric acid (HF) etching and silanization, whereas mechanical methods include sandblasting with 50 μm aluminum oxide (Al_2O_3) [16]. HF together with silane is the gold standard for conditioning the surfaces of computer-aided design/computer-aided manufacturing (CAD/CAM) glass-matrix ceramics and polymer-infiltrated ceramic-network materials (PICNs) [17,18]. HF etching forms an irregular pattern that promotes micromechanical retention [21–23]. However, HF has caustic and corrosive effects and poses a potential hazard to patients and physicians in the clinic [24–26].

Recently, a single-component ceramic conditioner, Monobond Etch & Prime (MEP, Ivoclar Vivadent, Liechtenstein) based on ammonium polyfluoride, was introduced in the dental market. This novel conditioner facilitates the simultaneous application of HF and silane to glass ceramics [27–29].

Lasers have been frequently used as an alternative surface treatment. The erbium, chromium:yttrium-scandium-gallium-garnet and erbium-doped yttrium aluminum garnet (Er:YAG) lasers have shown acceptable results [30–34]. The varying results obtained in the literature could be attributed to the different power, frequency, and duration of laser application [35].

A novel CAD/CAM hybrid ceramic material based on a PICN has been developed recently. The hybrid ceramic comprises a ceramic network (86 wt%) reinforced with an acrylate polymer network (14 wt%) [36]. Thus, the hybrid ceramic combines the positive properties of ceramics and composites [36,37].

The presence of protein, water, mineral content, temperature changes, and pH levels in the oral environment may cause differences in the bond strength values [38]. As no other study has examined these low-pH solutions simultaneously, we aimed to compare the bond strength in these environments.

Hence, this study evaluated the shear bond strength (SBS) between metal/ceramic brackets and two different CAD/CAM blocks subjected to various surface treatments (acid etching, bonding primer, sandblasting, and laser). The first null hypothesis tested was that the SBS of the brackets would not be affected by the type of material used, and the second was that the SBS would not be influenced by the surface conditioning method.

2. Materials and methods

The materials used in this study are shown in Table 1.

2.1. Specimen preparation

This study investigated the SBS of metal and ceramic brackets in certain solutions by subjecting different blocks fabricated using CAD/CAM systems to different surface treatments. For this purpose, we used two different CAD/CAM blocks, a lithium disilicate-reinforced glass ceramic block (GC LiSi) and a hybrid ceramic block (GC Cerasmart). In total, 300 specimens were fabricated via

Table 1
Manufacturer details and chemical composition of the materials in this study.

Materials	Manufacturer	Composition
GC LiSi (lithium disilicate-reinforced glass ceramic)	GC Europe, Leuven, Belgium	SiO_2 (57–80 %), Li_2O (11–19 %), K_2O (0–13 %), P_2O_5 (0–11 %), ZrO_2 (0–8%), ZnO (0–8%), and other oxides and ceramic pigments (0–10 %)
GC Cerasmart (PICN hybrid ceramic)	GC Europe, Leuven, Belgium	Bis-MEPP, UDMA, DMA, and 71 % silica (20 nm) and barium glass (300 nm) nano-particles by weight
Porcelain conditioner	Ultradent, USA	Hydrofluoric acid (9.6 %)
Monobond Etch & Prime	Ivoclar Vivadent, Liechtenstein	Tetrabutyl ammonium dihydrogen trifuoride, methacrylated phosphoric-acid ester, trimethoxysilylpropyl methacrylate, alcohol, and water
TransbondXT primer	3M, USA	Bis-GMA, TEGDMA, and triphenylantimony,4-(dimethylamino)-benzeneethanol
TransbondXT adhesive	3M, USA	Silane-treated quartz, Bis-GMA, EBPADMA, silane-treated silica, diphnyliodonium hexafuorophosphate

(PICN, polymer-infiltrated ceramic-network material; Bis-MEPP, 2,2-Bis(4-methacryloxypolyethoxyphenyl)propane; UDMA, urethane dimethacrylate; DMA, dimethacrylate; Bis-GMA, bisphenol A diglycidylether methacrylate; TEGDMA, triethylene glycol dimethacrylate; EBPADMA, ethoxylated bisphenol A dimethacrylate).

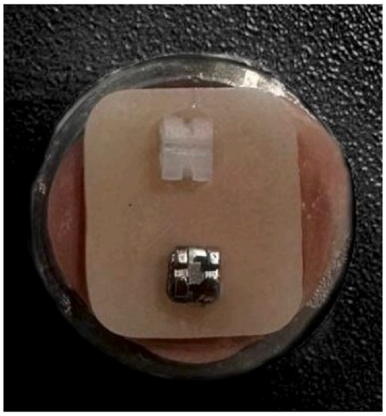

Fig. 1. Metal and ceramic brackets cemented on the test specimen.

underwater cutting (Isomet 1000, Buehler Ltd., Lake Bluff, IL, USA). The specimens were prepared according to the International Organization for Standardization (ISO) guidelines 11405-2003.

Stainless steel molds suitable for the Universal testing machine (Instron 3345, Instron Corp. Norwood, MA, USA) were prepared for the bonding test. A powdered acrylic polymer (Imicryl, SC, Konya, Turkey) was mixed with the liquid according to the manufacturer's instructions and poured into these standard molds when in the fluid state. Following this, 1.5 mm thick ceramic specimens were embedded in the acrylic, exposing only the surfaces to be treated. Thus, during the bonding test, the aim was to bring the metal tip to the ceramic–bracket interface, where the force would be applied. Metal and ceramic brackets were cemented onto the same specimen side-by-side (Fig. 1).

2.2. Surface treatment

The test specimens were divided into four groups according to the following surface treatments.

Surface conditioning methods were applied according to the manufacturer's instructions [40].

Control: No additional treatment was applied to the polished specimens.

HF etching: 9.6 % HF (Ultradent Porcelain Etch) was applied to the surfaces of the LiSi specimens for 20 s and Cerasmart specimens for 60 s. The samples were then rinsed under pressurized water for 60 s and dried for 30 s.

Intraoral sandblasting: The specimens were sandblasted with 50 μm Al_2O_3 from a distance of 10 mm under 90 psi pressure.

MEP: MEP was applied to the surfaces of the specimens for 20 s, allowed to interact for 40 s, and then rinsed.

Er:YAG laser: The surfaces of the specimens were irradiated using a 2-W Er:YAG laser at a speed of 10 Hz for 10 s. The applied laser had the following parameters: pulse energy, 200 mJ; power, 2 W; pulse length, 100 μs; pulses/s, 10 Hz; and energy density, 25.31 J/cm^2. The diameter of the applied laser tip was adjusted to 1 mm, the air level to 90 %, and the water level to 80 %. The laser was applied from a distance of 1 mm perpendicular to the surface of the specimens. The same operator performed the laser irradiation of all specimens.

After bonding with the orthodontic composite, they were stored in various solutions (saliva, mouthwash, and gastric juice), and the SBS values between the blocks and brackets were comparatively investigated.

2.3. Scanning electron microscope evaluation and surface roughness

The examination of the surface-treated specimens was conducted using a scanning electron microscope (SEM) (Zeiss Evo LS 10, Germany) with an emission power of 15 kV at 1000× magnification. The surface roughness of each specimen was measured using an optical profilometer (Zygo New View 7200, Ametek, CT, USA). After surface preparation, silane was applied to the treated ceramic surfaces, except for the specimens subjected to MEP.

2.4. Bonding

Mandibular central metal brackets (Mini Master Series, American Orthodontics, WI, USA) and mandibular central ceramic brackets (20/40, American Orthodontics, WI, USA) were bonded using an orthodontic adhesive resin (Transbond XT, 3M Unitek, CA, USA). They were then light-cured for 10 s using a light-emitting diode unit (standard mode: 1000 mW/cm^2; Valo Cordless, Ultradent, UT, USA).

After bonding with the orthodontic composite, the specimens were stored in distilled water at 25 °C. for 24 h. Thermal aging was performed for 5000 cycles at 5–55 °C.

2.5. Storage procedure

The specimens were then exposed to saliva, gastric juice (simulated gastric juice prepared using 0.113 % hydrochloric acid solution in deionized water), and mouthwash (Listerine Original, Johnson & Johnson Consumer Inc., Skillman, NJ, USA) under appropriate conditions. Metal and ceramic brackets were cemented onto the same specimen for evaluation under equal conditions.

2.6. SBS test

To measure the bond strength of the test specimens prepared, an SBS test was performed using the Universal testing machine (Instron 3345, Instron Corp. Norwood, MA, USA). The knife-edge chisel tip was positioned perpendicular to the edge of the base of the bracket (Fig. 2) and the load was applied at a crosshead speed of 0.5 mm/min according to the ISO/Technical Specification 11405-2003 standards [39]. The maximum force required to shear the button was recorded in Newtons and converted into megapascal (MPa).

2.7. SEM analysis

After the SBS test, the fracture lines of the specimens for each fracture type were visualized using an SEM (Zeiss Evo LS 10, Germany) at 20× magnification. The data obtained were statistically evaluated and compared between the groups.

2.8. Statistical analysis

To calculate the sample size of this study, the power of the test for each variable was determined as at least 80 %. The Shapiro–Wilk ($n < 50$) test was used to check whether the continuous measurements in the study were distributed normally; as the measurements were normally distributed, parametric tests were applied. Descriptive statistics for continuous variables are expressed as means and standard deviations. The analysis of variance (ANOVA) test was used to compare the SBS values according to surface treatment groups and solutions; the independent *t*-test was used to compare them according to the type of blocks and brackets. Following ANOVA, the Duncan test was used to identify different groups. Statistical Product and Service Solutions (IBM SPSS for Windows, version 26) software was used to conduct all statistical analyses; p-values <0.05 were considered statistically significant.

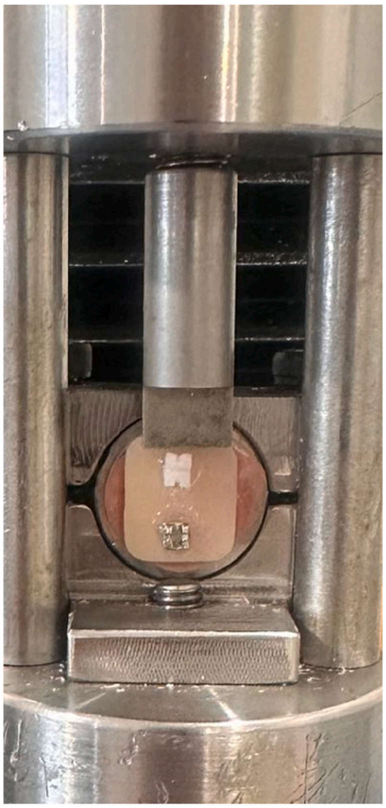

Fig. 2. The knife edge chisel tip was positioned to edge of base of bracket.

Table 2
Comparison of the shear bond strength values according to the surface conditioning treatments.

		Shear bond strength		[a]p-value
		Mean	SD	
Surface conditioning treatments	Control	4.359[c]	2.006	***0.001***
	Sandblasting	6.586[b]	1.823	
	HF	7.309[a]	2.290	
	Laser	4.061[c]	2.145	
	MEP	7.546[a]	0.860	
Solutions	Saliva	7.424[a]	2.307	***0.001***
	Gastric juice	4.622[c]	1.912	
	Mouthwash	5.870[b]	2.073	
Blocks	Cerasmart	6.651	1.844	***0.001***
	LiSi	5.294	2.670	
Brackets	Metal	6.032	2.346	*0.739*
	Ceramic	5.913	2.438	

(SD, standard deviation; HF, hydrofluoric acid; MEP, Monobond Etch & Prime).
[a] Significance levels according to one-way analysis of variance test or independent *t*-test results.
[b] ,b, cDifferences between the groups (Duncan post-hoc test).

3. Results

Table 2 shows the comparison results of the SBS values according to the surface conditioning groups, presenting a statistically significant difference between them ($p = 0.001$). The SBS was similar in the MEP and HF groups but differed from the other treatment groups with higher SBS values. Additionally, the SBS values of the control and laser groups were similar. The SBS value of the sandblasting group was different from that of the other groups.

Table 3 shows a comparison of the mean SBS values of the block types in the different surface conditioning groups. A statistically significant difference was observed in the SBS value according to the block type in the control ($p = 0.001$), sandblasting ($p = 0.001$), HF ($p = 0.026$), and laser groups ($p = 0.001$). The SBS was significantly higher in the Cerasmart block than in the LiSi block in the control, sandblasting, and laser groups. However, in the HF group, the SBS was significantly higher in the LiSi block than in the Cerasmart block. In contrast, no statistically significant difference was observed between the mean SBS values of the blocks in the MEP group ($p > 0.05$); the SBS values yielded similar results for both types of blocks.

Tables 4 and 5 show the comparison results of the mean SBS values of GC Cerasmart blocks with metal and ceramic brackets, according to the different surface conditioning treatment and solutions.

Tables 6 and 7 show the comparison results of the mean SBS values of GC LiSi blocks with metal and ceramic brackets, according to the different surface conditioning treatment and solutions.

3.1. SEM analysis

SEM analysis revealed microstructural variations among the ceramic surfaces subjected to different surface conditioning treatments (Figs. 3–5). When HF (Fig. 3B) and sandblasting (Fig. 3D) were applied to the GC LiSi blocks, clear morphological changes were observed. Crystals with defined cavities were observed clearly after the HF etching treatment. The surface of the GC Cerasmart blocks demonstrated dissolution of the crystalline particles after HF etching (Fig. 4). Fig. 4B showed that HF conditioning formed micropores on the Cerasmart surface. Additionally, Fig. 4D demonstrated that sandblasting created micro-sized elevated areas and crevices on the Cerasmart surface.

4. Discussion

This study aimed to determine the most reliable surface conditioning treatment for bonding metal and ceramic brackets to various CAD/CAM materials. The lithium disilicate glass ceramic and hybrid ceramic showed different results in this study. Moreover, the surface conditioning method affected the SBS values. Hence, the first and second hypotheses were rejected based on these findings.

The bond strength is important for the clinical success of orthodontic treatments. The SBS of metal and ceramic brackets bonded to different CAD/CAM blocks has been evaluated [41–46]. To the best of our knowledge, this is the first study comparing the SBS values of all bracket types in different mediums.

As previously reported, 6–8 MPa is considered the optimum bond strength and is clinically acceptable [9]. The goal of orthodontic bonding is to ensure sufficient bonding to withstand chewing and orthodontic forces, rather than maximum bonding, and simultaneously prevent material fracture when the brackets are removed at the end of the treatment [10]. In this study, the bond strength was

Table 3
Comparison of the shear bond strength values according to the block type in the surface conditioning groups.

	Groups	Block types				
		Cerasmart		LiSi		[a]*p-value*
		Mean	SD	Mean	SD	
Shear bond strength	Control	6.152	1.064	2.566	0.588	***0.001***
	Sandblasting	7.831	1.542	5.341	1.086	***0.001***
	HF	6.473	2.241	8.145	2.073	***0.026***
	Laser	5.429	2.136	2.693	0.973	***0.001***
	MEP	7.368	0.897	7.723	0.807	*0.220*

(SD, standard deviation; HF, hydrofluoric acid; MEP, Monobond Etch & Prime).
[a] Significance levels according to the independent *t*-test results.

Table 4
Comparison of the shear bond strength values of GC Cerasmart blocks with metal brackets according to the surface conditioning treatment groups and solutions.

	Solutions	Surface conditioning groups										
		Control		Sandblasting		HF		Laser		MEP		[a]*p-value*
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Shear bond strength	Saliva	$7.442^{A,a}$	0.100	$9.671^{A,a}$	0.100	$7.948^{C,c}$	0.050	$8.063^{A,c}$	0.043	$9.070^{A,b}$	0.045	***0.001***
	Gastric juice	$4.861^{C,b}$	0.107	$6.899^{C,a}$	0.099	$4.327^{B,c}$	0.100	$3.780^{B,d}$	0.100	$6.745^{B,a}$	0.099	***0.001***
	Mouthwash	$6.769^{B,c}$	0.101	$7.323^{B,a}$	0.101	$7.052^{A,b}$	0.050	$4.051^{B,d}$	0.045	$6.874^{B,c}$	0.091	***0.001***
[c]***p-value***		***0.001***		***0.001***		***0.001***		***0.001***		***0.001***		

[A, B, C] Differences between solutions (Duncan post-hoc test) ↓
(SD, standard deviation; HF, hydrofluoric acid; MEP, Monobond Etch & Prime).
[a] Level of significance between the groups according to the one-way analysis of variance test.
[b] ,b,cDifference between the groups (Duncan post-hoc test) →
[c] Level of significance between solutions according to the one-way analysis of variance test.

Table 5
Comparison of the shear bond strength values of GC Cerasmart blocks with ceramic brackets according to the surface conditioning treatment groups and solutions.

	Solutions	Surface conditioning groups										
		Control		Sandblasting		HF		Laser		MEP		[a]*p-value*
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Shear bond Strength	Saliva	$7.115^{A,e}$	0.083	$9.875^{A,b}$	0.091	$10.112^{A,a}$	0.086	$8.637^{A,c}$	0.097	$7.865^{B,d}$	0.094	***0.001***
	Gastric juice	$4.865^{C,c}$	0.065	$5.669^{C,b}$	0.091	$3.757^{C,e}$	0.093	$3.937^{B,d}$	0.043	$6.539^{B,a}$	0.102	***0.001***
	Mouthwash	$5.860^{B,c}$	0.097	$7.547^{B,a}$	0.090	$5.642^{B,d}$	0.095	$4.105^{B,e}$	0.018	$7.116^{A,b}$	0.083	***0.001***
[c]***p-value***		***0.001***		***0.001***		***0.001***		***0.001***		***0.001***		

[A, B, C] Differences between solutions (Duncan post-hoc test) ↓
(SD, standard deviation; HF, hydrofluoric acid; MEP, Monobond Etch & Prime).
[a] Level of significance between the groups according to the one-way analysis of variance test.
[b] ,b,cDifference between the groups (Duncan post-hoc test) →
[c] Level of significance between solutions according to the one-way analysis of variance test.

greater than 6 MPa in the HF, sandblasting, and MEP-treated groups in the saliva medium.

The bonding of orthodontic brackets to ceramics can be influenced by some factors such as adhesive properties, bracket material, type of porcelain, bracket base design, surface conditioning method and thermocycling [40,47].

The highest SBS was reported for the hybrid ceramic in our study, which was similar to the findings of Buyuk and Kucukekenci [20]. The hybrid ceramic showed a higher SBS than the lithium disilicate glass ceramic. These results are similar to those of a previous study by Ghozy et al. [47].

The findings of this study revealed no significant difference between metal and ceramic brackets, which corroborates the findings of Alhaija et al. [48]. This could be attributed to the weaker bond between the cement and ceramic restoration compared with that between the cement and bracket.

For orthodontic applications, 5–9% HF etching for 60 s in combination with silane is recommended to create micromechanical and chemical retention for bonding brackets [39,40]. Sandblasting with Al_2O_3 is known to increase the surface area, micro-crack formation, and mechanical retention [16]. Lasers offer an alternative method for etching surfaces to reinforce the bond between the brackets and materials [30,32].

Table 6
Comparison of the shear bond strength values of GC LiSi blocks with metal brackets according to the surface conditioning treatment groups and solutions.

	Solutions	Surface conditioning groups										
		Control		Sandblasting		HF		Laser		MEP		[a]*p-value*
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Shear bond Strength	Saliva	$3.147^{A,e}$	0.101	$6.218^{A,c}$	0.100	$9.875^{A,a}$	0.091	$4.238^{A,d}$	0.091	$7.957^{A,b}$	0.053	***0.001***
	Gastric juice	$1.870^{C,d}$	0.092	$3.538^{C,c}$	0.092	$6.341^{B,b}$	0.092	$1.862^{C,d}$	0.095	$6.551^{B,a}$	0.090	***0.001***
	Mouthwash	$2.071^{B,e}$	0.045	$5.637^{B,c}$	0.097	$9.549^{C,a}$	0.090	$3.115^{B,d}$	0.090	$8.111^{A,b}$	0.088	***0.001***
[c]***p-value***		***0.001***		***0.001***		***0.001***		***0.001***		***0.001***		

[A, B, C]Differences between solutions (Duncan post-hoc test) ↓
(SD, standard deviation; HF, hydrofluoric acid; MEP, Monobond Etch & Prime).
[a] Level of significance between the groups according to the one-way analysis of variance test.
[b] ,b,cDifference between the groups (Duncan post-hoc test) →
[c] Level of significance between solutions according to the one-way analysis of variance test.

Table 7
Comparison of the shear bond strength values of GC LiSi blocks with ceramic brackets according to the surface conditioning treatment groups and solutions.

	Solutions	Surface conditioning groups										
		Control		Sandblasting		HF		Laser		MEP		[a]*p-value*
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Shear bond Strength	Saliva	$3.319^{A,d}$	0.091	$6.221^{A,c}$	0.091	$10.109^{A,a}$	***0.001***	$3.140^{A,e}$	0.097	$8.461^{A,b}$	0.102	***0.001***
	Gastric juice	$2.120^{C,d}$	0.090	$4.287^{B,c}$	0.155	$4.653^{C,b}$	***0.001***	$1.344^{C,e}$	0.101	$8.502^{A,a}$	0.020	***0.001***
	Mouthwash	$2.870^{B,d}$	0.092	$6.147^{A,c}$	0.100	$8.345^{B,a}$	***0.001***	$2.462^{B,e}$	0.103	$6.759^{B,b}$	0.103	***0.001***
[c]***p-value***		***0.001***		***0.001***		***0.001***		***0.001***		***0.001***		

[A, B, C]Differences between solutions (Duncan post-hoc test) ↓
(SD, standard deviation; HF, hydrofluoric acid; MEP, Monobond Etch & Prime).
[a] Level of significance between the groups according to the one-way analysis of variance test.
[b] ,b,cDifference between the groups (Duncan post-hoc test) →
[c] Level of significance between solutions according to the one-way analysis of variance test.

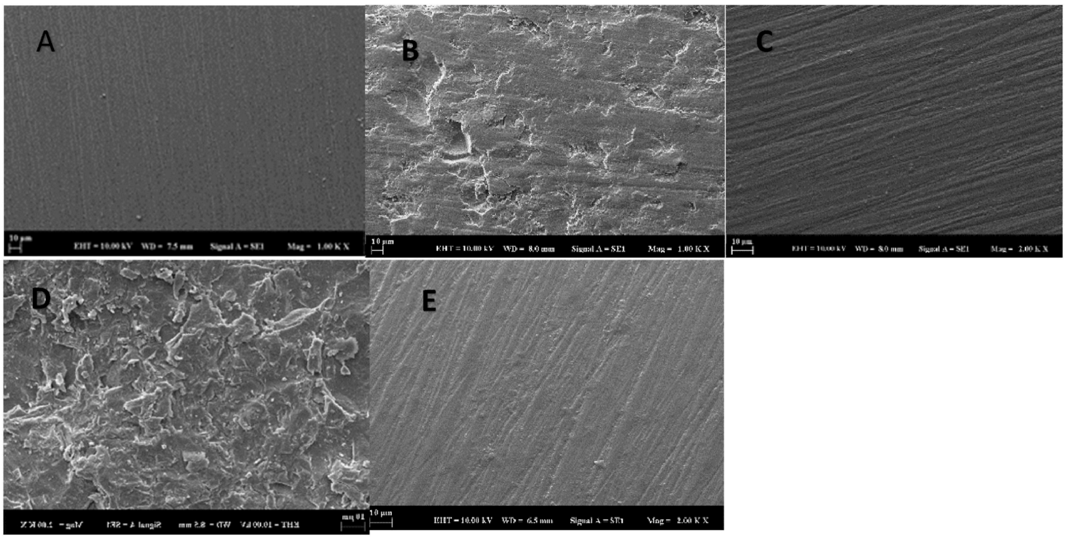

Fig. 3. Scanning electron microscope images of the GC LiSi blocks (2000× magnification) under different surface conditioning treatments A) Control; B) Hydrofluoric acid etching; C) Monobond Etch & Prime; D) Sandblasting; E) Laser.

These findings indicate that HF application elicited the best results in lithium disilicate glass ceramics, which corroborates the findings of previous studies [43,45,46]. A reasonable explanation for this outcome is the regular microporosity created by HF in the glass matrix.

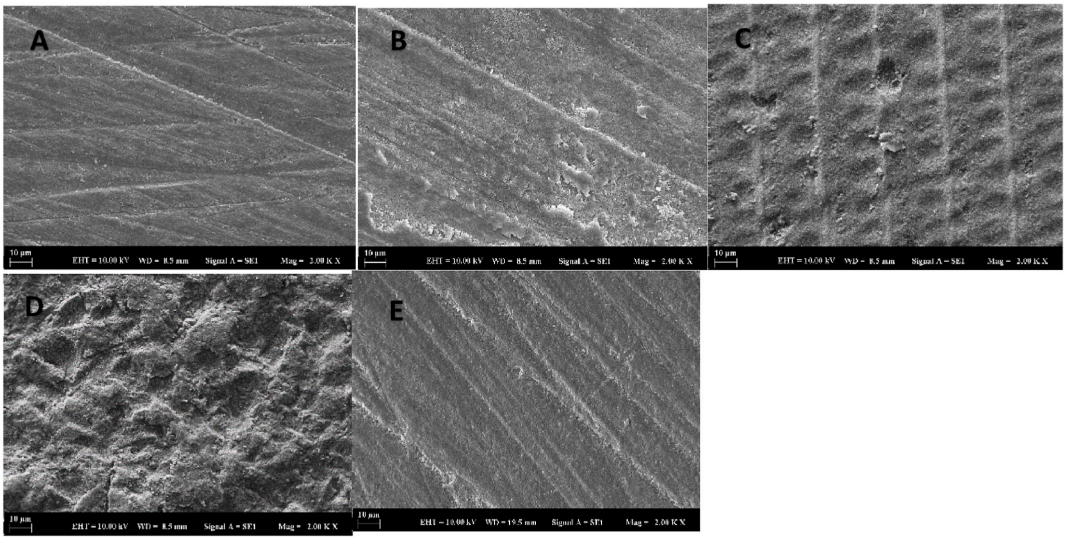

Fig. 4. Scanning electron microscope images of the GC Cerasmart blocks (2000× magnification) under different surface conditioning treatments.

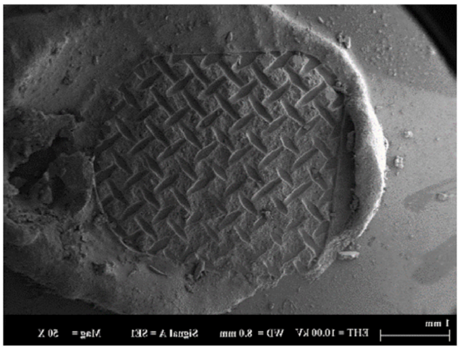

Fig. 5. Scanning electron microscope image of the retention mechanism of the orthodontic brackets with a metallic mesh at the metal bracket base (50× magnification).

Notably, sandblasting is the best conditioning method for hybrid ceramics. We can interpret that the sandblasting process creates better bonding because of the polymer structure, which is resistant to acidification.

Our study revealed that HF increased the SBS of the Cerasmart blocks to a greater extent than that of the LiSi blocks. Similarly, it was concluded that sandblasting had a better effect on the SBS of the Cerasmart blocks than of the LiSi blocks. This could be because the sandblasting process has a better effect on the polymer structure.

Laser treatment yielded clinically acceptable values only for the Cerasmart blocks. The lowest SBS values were obtained for the laser-treated groups for both block types. The SBS of the LiSi block was lower than that of the Cerasmart block in the laser group because the laser process was less effective due to the dense glass content of the LiSi block.

When we compared the SBS according to the solutions, we observed that the highest SBS values were obtained in the saliva medium, followed by mouthwash and gastric juice. It is clear that intraoral conditions can affect the orthodontic dynamics. The bond strength in mouthwash and gastric juice environments is below the average value of 6 MPa. Gastric juice has the lowest bonding strength because of its low pH and the presence of organic and inorganic components. Therefore, the harmful effects of gastric juices may cause bracket ruptures in individuals diagnosed with severe gastroesophageal reflux. The SBS value of 4.6 MPa obtained in the gastric juice environment in our study is not clinically acceptable.

Thermocycling, wet storage and mechanical fatigue are aging methods to simulate intraoral conditions. Thermal cycling was used to determine changes of temperature can affect the reduction of the bond strength between bracket-ceramic. [The decrease in mechanical properties can be explained by water reaching the bracket-bond interface and the sudden temperature drop seen in materials with different thermal coefficients, creating thermal stresses at the interfaces. Besides, thermocycling can cause mechanical stress at bonding area, causing volumetric changes.

The SBS values of the groups were confirmed using SEM. In our study, MEP generally resulted in a less roughened surface and a less marked dissolution pattern, compared with HF etching of the GC LiSi blocks, similar to the findings of other studies [45,46]. In the GC

Cerasmart blocks, HF conditioning showed a more obvious dissolution pattern than that of MEP.

Thus, both the CAD/CAM materials used in this study achieved clinically acceptable SBS values when subjected to appropriate pretreatments and in the appropriate oral environments. Nevertheless, the comparison of SBS of other CAD/CAM blocks with different compositions is warranted in future studies. Additionally, one limitation of this study is that only one brand of adhesive resin was tested. Another limitation is that the specimens were prepared with a flat surface. Further studies should be conducted on specimens conforming to the anatomical form.

5. Conclusions

Considering the study limitations, we can conclude that SBS is affected by the type of CAD/CAM restoration and surface conditioning treatment. No statistically significant difference was observed in the SBS between the metal and ceramic brackets.

The Cerasmart block provided a higher SBS than that in the LiSi block. HF etching yielded the best results with the LiSi blocks. Notably, sandblasting resulted in a higher SBS in the Cerasmart blocks than in the LiSi blocks. Furthermore, MEP was an effective pretreatment method for both the CAD/CAM materials used in this study. Finally, mouthwash and gastric juices were revealed to lower the SBS.

CRediT authorship contribution statement

Şevki Çınar: Writing – original draft, Supervision, Project administration, Investigation, Conceptualization. **Bike Altan Çınar:** Writing – review & editing, Supervision, Project administration, Methodology. **Gökçe Güneş Bağlan:** Methodology, Investigation, Formal analysis. **Ersin Yıldırım:** Supervision, Data curation, Conceptualization.

Data availability statement

The data have been deposited into a publicly available repository.
Accession: https://figshare.com/s/1da1be2fb61e5031478e.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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