Original Article

Shear Bond Strength, Tie-wing Fracture Resistance, and Frictional Resistance of a Custommade Ceramic Bracket Version 1

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Abstract

Objectives: Shear bond strength (SBS), tie-wing fracture resistance (Tie-wing FR), and frictional resistance of a custom-made ceramic orthodontic bracket version 1 (CC bracket v1) were evaluated.

Methods: CC bracket v1 and its mould were designed by incorporating average buccal surface-curvature of Thai premolars into its base and fabricated by injection-moulding technique. SBS, Tie-wing FR and static frictional resistance of CC bracket v1 were compared to those of a commercial ceramic bracket (N=10). Normally distributed data were compared between groups using t tests.

Results: SBS means were significantly different between CC bracket v1 and controls (17.25±5.63 MPa and 24.75±5.29 MPa, respectively, $p < 0.05$). Tie-wing FR was significantly lower for CC bracket v1 (41.74±5.34 MPa) than the controls (89.48±15.93). Frictional resistance was significantly greater for CC bracket v1 (141.93±35 gf) vs. controls (86.83±25.4 gf).

Conclusions: CC bracket v1 exhibited lower SBS and Tie-wing FR but clinically acceptable. However, its frictional resistance needs improvement.

Keywords: bracket base, ceramic bracket, fracture resistance, frictional resistance, shear bond strength

Introduction

Concerning in aesthetics has led to an increase in the development of aesthetic orthodontic appliances. The curvature of the base of ceramic orthodontic brackets is generally designed to conform to tooth anatomy. Commercial ceramic brackets mostly have the base curvature conformed to Caucasian tooth surfaces. If they are used in different population, it can result in unprecise direction of forces exerting on the tooth.(1) Thonggerd *et al.,*(2) reported that the average buccal surface curvature of the upper premolars of Thai individuals was less curved than the surface curvature of a commercial bracket base, for which the mean difference reached 0.07558 mm. (Figure 1). The authors described that the occluso-gingival curvature of the tooth differed more than the mesio-distal aspect, which suggested that this difference could affect the precision of torque and rotational movement even though the bracket was bonded in the correct position. In addition, when the bracket base did not conform to the tooth surface, it could result in un-uniform thickness of adhesive at the tooth-bracket base interface which could be a cause of bond failure.(3) Using digital surface scanning technology, a custom-made ceramic bracket can be designed by incorporating the average tooth curvature of specific samples into the bracket base. This should improve the precision of tooth movement and reduce the adhesive thickness, which may result in better interfacial shear bond strength between the tooth and the bracket base.

To address this issue, an initial version of a custom-made aluminium oxide ceramic orthodontic bracket was designed and developed by incorporating mean curvature of buccal surface of upper premolars, derived from Thai samples, into the bracket base.(4) Continuing to the previous study(4), version one of the custom-made ceramic bracket (CC bracket v1) was developed by altering its design while maintaining the curvature of the bracket base as our previous study.(4)

The CC bracket v1 was improved to prevent bracket-wing fracture during fabrication process. It was designed to have more round corners without sharp angles in order to obtain better stress distribution when disengaging its mould during fabrication. To achieve an optimal bond strength, the mechanical retention at the bracket base was increased by adding irregularly shaped aluminium oxide ceramic crystals to the bracket base.

The bracket was made of polycrystalline aluminium oxide ceramic material previously developed by Wasanapiarnpong *et al.,*(5) which offered appropriate mechanical properties for ceramic brackets, including high fracture toughness, transparency, and biocompatibility.

The CC bracket v1 was fabricated using injection-moulding technique and sintering process. A mould of the CC bracket v1 (Figure 2) was developed by an engineering team at the Thai-German Institute of Technology using a reverse engineering process. To enhance the success rate of fabrication and prevent fracture of the bracket wings during disengagement of the mould pieces, a custom-made mould was designed. This stainless steel mould also accounted for 25% shrinkage of the ceramic material during the sintering process.(4) This study extended the benefits of surface-scanning technology to develop custom-made ceramic orthodontic brackets for use in individuals or specific populations in the future.

Adequate bond strength to tooth surface, high fracture toughness of the tie-wings of the brackets, and low frictional resistance to the wires are considered basic mechanical requirements of the orthodontic ceramic brackets. The objectives of this study were to compare the mechanical properties of CC bracket v1 and a commercial ceramic bracket in terms of shear bond strength (SBS), tie-wing fracture resistance (Tie-wing FR), and static-frictional resistance (S-FR).

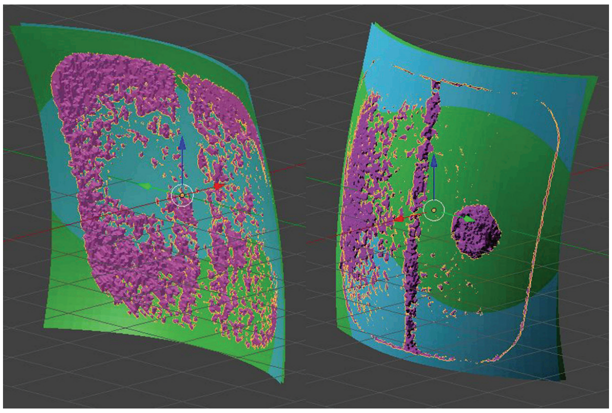

Figure 1: The difference between the average curvature of the buccal surface of the upper premolars of samples from Thai individuals (blue) and curvature of the commercial bracket base (green and purple). Purple represents the rugged curvature of the real base in the commercial ceramic bracket, whereas green represents a commercial bracket's curvature in a fit curve pattern closely resembling the ultimate curvature of the purple.

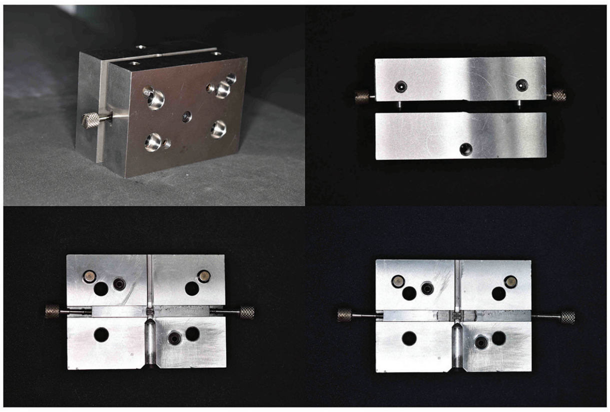

Figure 2: The metal mould of CC bracket v1. There are two separating compartments with handles that can be pulled apart to prevent ceramic bracket fracture during fabrication.

Materials and Methods

Fabrication of the custom-made ceramic bracket version 1

The material composition of the CC bracket v1 consisted of magnesium aluminium oxide ($MgAl_2O_4$), polyethylene glycol (PEG), polyvinylbutyral, and stearic acid. These components were mixed in two cycles and compressed using an injection-moulding technique to obtain the desired shape. The process began by injecting lubricating oil into the mould, which was heated to 200 degrees Celsius. The mixture was then injected into the mould at a temperature of 210 degrees Celsius. The mould was cooled to room temperature, and the brackets were carefully removed from the mould. The brackets were soaked in distilled water for 24 hours to dissolve the remaining PEG.

To enhance the retention property of the bracket base, a mixture of 100-300 nm $MgAl_2O_4$ powder and ethanol at a 50:50 ratio by weight was prepared. The mixture was applied to the base of the bracket using a fine-tip brush under a 10X magnifying scale loupe. After allowing the ethanol to completely evaporate, the bracket was heated at approximately 500 degrees Celsius for one hour to remove the remaining binders. The temperature was raised to 1,650 degrees Celsius at a rate of 5 degrees Celsius per minute and maintained for 2 hours before allowing the bracket to cool naturally in an electric furnace. Then, the bracket was removed from the electric furnace, and the external surfaces were polished with a superfine diamond bur.

Mechanical properties

Shear bond strength test

The SBS test was performed according to Thonggerd *et al.,*[4] and Suliman *et al.,*[6] This research was approved by the University Human Ethics Committee (SWUEC-384/2564X). Twenty unidentified upper premolars were anonymously collected from a hospital and dental clinics and were kept in accordance with the standards of ISO 3696:1987. Inclusion criteria of the samples was a sound tooth with a definite cemento-enamel junction. The exclusion criteria for sample collection were enamel cracks, any signs of caries, abfraction, abrasion, an enamel craze line, enamel hypoplasia, demineralization, or fillings on the crown or root.[7]

The tooth samples were prepared by mounting the root in 1×1×1 inch^3 dental die stone blocks that were allowed to set completely in a humidified box.

The samples were randomly divided into 2 groups (10 teeth per group). Group 1 included CC brackets v1, and Group 2 served as the control group (a commercial ceramic brackets with 022" slot; Clarity Advanced™, 3M Unitek, Monrovia, USA). The tooth surfaces were polished, etched with 37% phosphoric acid (3M Unitek) for 30 seconds[4], and air-blown until a chalky white appearance was revealed. The primer was applied (Transbond XT™, 3M Unitek, Monrovia, USA) on the tooth surface and air-thinned for 10 seconds. An adhesive bonding agent (Transbond XT™, 3M Unitek, Monrovia, USA) was applied to the tooth surfaces and at the bases of the brackets. The brackets were positioned on the tooth surfaces in the middle of the crown in occluso-gingival and mesio-distal dimensions. The brackets were placed with a hand instrument and pressed with 5 N force, which was measured using a force gauge. The excess adhesive was removed, and the adhesive was cured with LED light (Mini-LED Satelec, Acteon, Mount Laurel, USA) for 20 seconds on each side.[4] After bonding, the specimens were stored in 37°C distilled water[4,6] for 24 hours before testing.

The specimens were fixed on a stand of a universal testing machine (EZ test, Shimadzu, Japan), and the level of the bracket's wing was aligned parallel to the direction of the applied force and knife-edge blade of the testing machine (Figure 3). The SBS was tested at a cross-head speed of 1 mm per minute[4] until the bonding between the bracket and the tooth surface was broken. The failure load was recorded and reported as megapascals by dividing the failure load value by the surface area of the bracket base. After the SBS test, all specimens were evaluated using the adhesive remnant index (ARI)[8] obtained using optical microscopy at a magnification of 20. The failure load and ARI score were statistically analysed.

ARI index was categorized into 0-3 scores, as follows:

- 0, no adhesive left on tooth
- 1, less half of the adhesive left on the tooth
- 2, more than half of the adhesive left on the tooth
- 3, all the adhesive left on tooth with mechanical pattern visible[8]

Tie-wing fracture resistance test

Tie-wing FR was tested using methods adopted from Thonggerd *et al.,*[4] and Johnson *et al.,*[9] Ten samples from Group 1 (CC bracket v1) and Group 2 (controls) were tested and compared.

Each bracket was fixed on acrylic blocks with resin adhesive (Transbond XT™, 3M Unitek) (Figure 4A) and attached to a platform of the testing machine. The ceramic bracket was held with a 0.012-inch ligature wire at the horizontal slot (Figure 4B). The retention of specimens was enhanced by embedding the gingival part of the bracket into the acrylic resin (Figure 4C). Disto-incisal wing of the bracket was tied with a 0.012-inch ligature wire, and both ends were attached to the loading part of the universal testing machine (Figure 4D). The Tie-wing FR was measured in tensile mode at a cross - head speed of 10 mm per minute until the bracket wings fractured (Figure 4E). The tensile force value was recorded in Newtons and converted to megapascal by dividing the failure load value by the contact area between the ligature wire and the tie-wings.

Frictional resistance test

The static frictional resistance (S-FR) test was modified from Jian-Hong Yu *et al.,*[10] and Tribumrungsuk *et al.*[11] Ten samples from Group 1 (CC bracket v1) and Group 2 (controls) were tested. The S-FR between the slot surface of the ceramic bracket and the 7 cm length of 0.019”×0.025” stainless steel wire was recorded with a universal testing machine.

Each ceramic bracket was fixed on a metal plate, positioned at a mark point and a jig to ensure that the wire and the bracket slot were parallel to each other with 0-degree torque, and then ligated with an elastomeric ring (3M Unitek). The upper end of a 0.019”×0.025” stainless steel wire was attached to the upper compartment of the testing machine (Figure 5).

After the specimen was prepared, the machine pulled the wire through the bracket slot using a 50 N load cell and a crosshead speed of 2 mm per minute. The frictional force–displacement curve was plotted, and the peak of the static frictional force was recorded and statistically evaluated.

Scanning electron microscopy (SEM)

The bracket surface was attached to the sample base and coated with gold. The surface of each bracket was analysed using SEM (JSM, 6480LV, JEOL™) to investigate the grain size, shape, homogeneity of the $MgAl_2O_4$ crystals, and the bracket surface roughness.

Data analysis

Statistical analysis was performed using SPSS version 27.0 (SPSS Inc., Chicago, Illinois, USA). Shapiro–Wilk test results showed that the data were normally distributed, differences between the two groups were analysed using the independent t test. The chi-square test was used to compare the ARIs of each group. The statistical significance level was set at $p<0.05$.

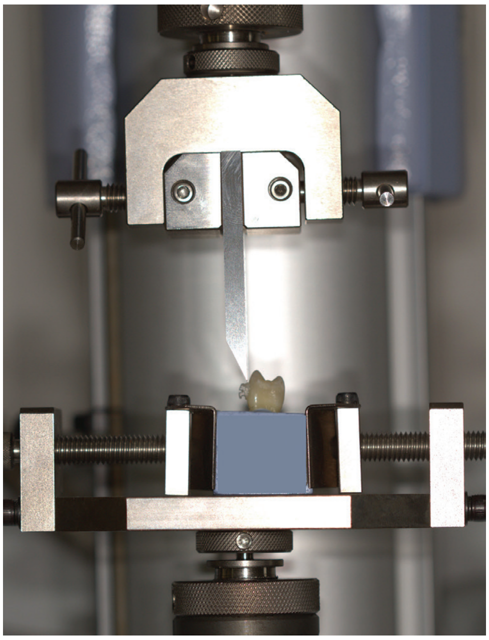

Figure 3: The shear bond strength test was performed using a universal testing machine (EZ test, Shimadzu, Japan) at a cross - head speed of 1 mm per minute.

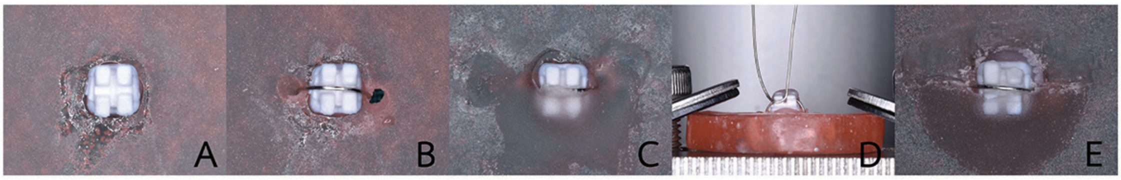

Figure 4: The specimen preparation process (A-C) and the Tie-wing fracture resistance test using a universal testing machine (D and E) (EZ test, Shimadzu, Japan).

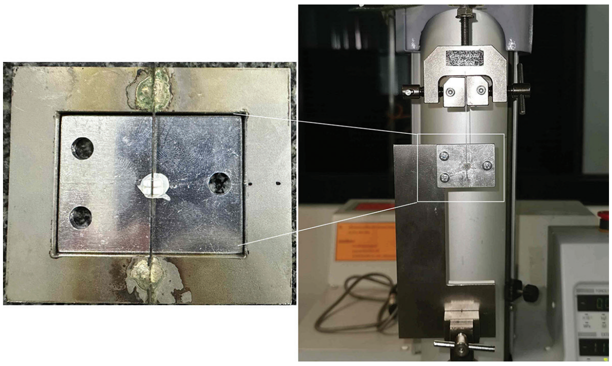

Figure 5: Frictional resistance was tested using the universal testing machine (EZ test, Shimadzu, Japan).

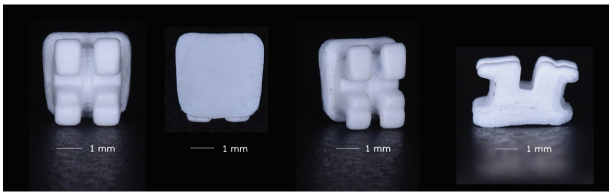

Figure 6: The custom-made ceramic bracket version 1.

Results

Fabrication of the custom-made ceramic bracket version 1

The CC bracket v1 showed no excess ceramic beneath the tie-wing area, and the horizontal slot size was appropriate for a 0.019”×0.025” stainless steel wire (Figure 6).

Mechanical properties

Shear bond strength and ARI tests

The SBS means of Group 1 (CC bracket v1) and Group 2 (controls) were 17.25±5.63 MPa and 24.75±5.29 MPa, respectively. Statistical analysis indicated a significant difference (p<0.01) in the SBS between the two groups (Table 1). Group 2 showed patterns of debonding with ARI scores ranging from 1 to 3, whereas the ARIs of Group 1 ranged from 2 to 3. A score of 3 was the most frequently observed in Group 1. Statistical analysis indicated no significant difference in the ARI scores between the two groups (p>0.05) (Table 2).

Tie-wing fracture resistance

The means of the Tie-wing FR of Group 1 (CC bracket v1) and Group 2 (controls) were 41.74±5.34 MPa and 89.48 ± 15.93 MPa, respectively. Statistical analysis indicated a significant difference (p<0.001) in Tie-wing FR between the two groups (Table 3).

Static frictional resistance

The mean S-FR of Group 1 (CC bracket v1) was 141.94±35 gm, whereas Group 2 (controls) had a mean S-FR of 86.83±25.4 gm. Statistical analysis revealed a significant difference (p<0.001) in the static frictional resistance between the two groups (Table 4).

Scanning electron microscopy (SEM)

SEM evaluation revealed that the crystals at the base of the commercial ceramic bracket were larger in size than the $MgAl_2O_4$ crystals found on the base of CC bracket v1 (Figure7). SEM analysis of the surface roughness revealed that the commercial ceramic bracket had grain sizes mostly less than 10 µm, whereas CC bracket v1 had grain sizes exceeding 50 µm (Figure 8).

Discussion

Fabrication of the custom-made ceramic bracket version 1

Digital technology can be applied to the manufacturing of orthodontic appliances. This study aimed to incorporate scanning surface technology to design a custom-made ceramic bracket with a base that has anatomical curvature conforming to a group sample from a specific population. The injection mould used to produce the custom-made ceramic bracket was constructed using reverse engineering and 3D printing of stainless steel. The ceramic injection and sintering processes used to fabricate the

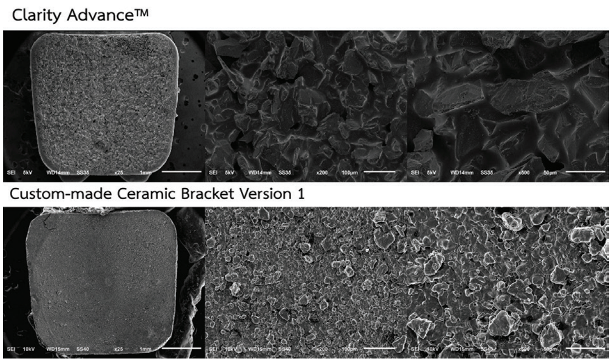

Figure 7: Surface of bracket base of the commercial ceramic bracket and the CC bracket v1 in magnification of 25×, 200× and 500×. The crystals at the base of the Clarity bracket were larger in size compared to the $MgAl_2O_4$ crystals found on the CC bracket base.

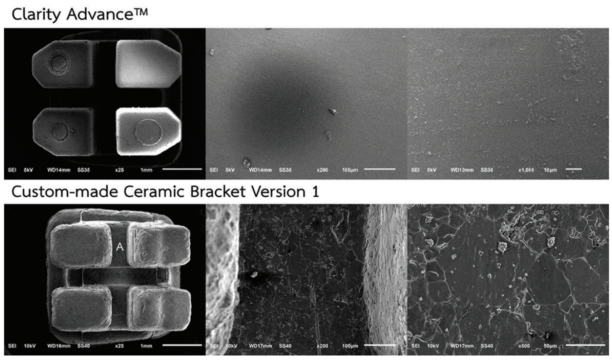

Figure 8: Surface roughness of the commercial ceramic bracket and the CC bracket v1 (Bracket slot; A) at 25×, 200× and 500× magnification.

Table 1: Comparison of the SBS means between CC bracket v1 and the controls (Clarity Advance™).

	Cross section area of bracket base (mm^2)	Mean SBS (MPa)	Range (MPa)	*p*-value
Group 1 (CC bracket v1)	12.8	17.25±5.63	7.51-26.86	.008**
Group 2 (Controls: Clarity Advance™)	11.69	24.75±5.29	18.14-31.33	

***p*<0.01, independent *t*-test

Table 2: Comparison of the ARI scores between CC bracket v1 and the controls (Clarity Advance™).

ARI score	0	1	2	3	*p*-value
Group 1 (CC bracket v1)	0%	0%	25%	75%	.074
Group 2 (Controls: Clarity Advance™)	0%	37.5%	37.5%	25%	

**p*>0.05, Chi square *t*-test

Table 3: Comparison of mean tie-wing fracture resistance between the CC bracket v1 and the controls (Clarity Advance™).

	Mean fracture resistance (N)	Area of touched wire (mm^2)	Mean fracture resistance (MPa)	Range (MPa)	*p*-value
Group 1 (CC bracket v1)	16.69±2.17	0.4	41.74±5.34	32.1-51.86	.000***
Group 2 (Control: Clarity Advance)	35.79±6.38	0.4	89.48±15.93	68.73-115.05	

****p*<0.001, Independent *t*-test

Table 4: Showed comparison of means static frictional resistance between the CC bracket v1 and the controls (Clarity Advance™).

	Mean of Frictional Resistance (gm)	Range (gm)	*p*-value
Group 1 (CC bracket v1)	141.94±35	92.05–189.36	.000***
Group 2 (Controls: Clarity Advance™)	86.83±25.4	54.15–148.34	

****p*<0.001, Independence *t*-test

custom-made bracket can be performed in an in-house laboratory. This study showed the potential benefits of digital technology for the fabrication of custom-made ceramic brackets for individuals in the future.

A limitation of this study is the absence of a validated method to accurately assess whether the curvature of the base conforms to the mould, which should be addressed in future research.

Shear bond strength

Adequate shear bond strength between the bracket base and tooth surface is pivotal for the delivery of effective forces in orthodontic treatment. A higher SBS is not always favourable; on the other hand, an optimal bond strength is preferred to prevent premature loss of the brackets as well as to prevent enamel loss in the debonding process.(6) According to a study by Reynold(12), the minimum SBS required for successful clinical orthodontic bonding was 5.88-7.85 MPa. Zepperi *et al.,*(13) reported that the clinically acceptable SBS ranged from 13 to 21 MPa. The results of this study showed that the average SBS of CC bracket v1 was greater than the minimum clinically acceptable SBS reported by Reynold(12) and within the clinically acceptable range reported by Zepperi *et al.*(13)

The debonding pattern revealed by the ARI index analysis indicated that the debonding stress of CC bracket v1 was concentrated at the interface between the bracket base and adhesive material (ARI-2, ARI-3). In contrast, given the higher SBS in the Clarity Advance group, the debonding stress was equally concentrated at the bracket base–adhesive interface (ARI-2=37.5%) and enamel–adhesive interface (ARI-1=37.5%), which could increase the risk of enamel damage during bracket debonding. According to Retief *et al.,*(14) 13.5 MPa was the minimum bond strength at which enamel damage could occur during the debonding process. This study showed that the average SBS of the Clarity Advance was greater than 13.5 MPa, so bond failure at the enamel–adhesive interface was frequently observed, indicating good bonding to enamel but a greater risk of enamel loss. Although there was no statistically significant difference in the ARI values between the two groups, ARI-3 was the most frequently observed in the CC bracket v1 group (ARI-3= 75%). These findings suggested that the CC bracket v1 could contribute to a lower risk of enamel damage during debonding but still had a clinically acceptable SBS.

The shear bond strength between ceramic bracket and enamel can be affected by many factors, including the pattern and size of the bracket base.(15-17) A previous study(4) suggested that the irregularity and consistency of $MgAl_2O_4$ crystals at the bracket base might affect the bond strength. SEM analysis revealed that the crystal particles at the base of CC bracket v1 were irregular in shape. Large crystals at the CC bracket v1 base provided extensive undercuts or irregularities on the surface. These undercuts offered additional surface area for the adhesive resin to mechanically interlock and form a stronger bond with the tooth surface, leading to optimum SBS. Studies of ceramic bracket base designs(15-16) reported that a bracket with 50 μ-round glass particles incorporated onto its alumina base showed the highest SBS of 24.7±1.9 MPa. The results suggested that these beads had adequate undercuts for mechanical interlocking of the adhesive resin, which could increase the bonding ability. Based on the SEM study (Figure 7), the crystals at the base of the Clarity bracket were larger in size than the $MgAl_2O_4$ crystals found on the base of the CC bracket v1. Specifically, the average size of the crystals in the Clarity bracket base was within the range of 20 to 100 μm, whereas the average size of the crystals in the CC bracket v1 base was less than 25 μm. Therefore, discrepancies in the crystal sizes could be a factor involved in the lower SBS observed in CC bracket v1. The next version of the CC bracket base might be improved by increasing the size of the $MgAl_2O_4$ crystals to create more undercuts for mechanical retention and to enhance the optimal SBS of the bracket.

A study by Newman(17) reported that a larger bracket base led to increased bond strength. The size of the bracket base of CC bracket v1 was 12.8 mm^2, which was larger than the size of the Clarity Advance bracket (11.69 mm^2). However, the results of this study did not correspond to those of the study by Newman.(17) Thus, the irregularity of the crystalline grains of ceramic materials at the bracket base might have a greater effect on SBS than the surface area of the bracket base.

Apart from shear bond strength, dissimilarity of the occluso-gingival aspect of the curvature between the commercial ceramic bracket base and the buccal surface of the upper premolars of Thai individuals could impact torque and rotational movement.(2) Nevertheless, effects of differences between various types of bracket base including that of the CC bracket v1 and the anatomical surface of a tooth on torque and rotational movements should be further investigated in future studies.

Tie-wing fracture resistance

Ceramic bracket fractures are associated with material property of aluminium oxide to withstand multiple direct forces. Resistance to breakage additionally relies on the specific type, shape, grain size, overall volume, and quality of the manufacturing process of the ceramic brackets.(18-27)

Sharp outlines and pointed angles at the corner of the ceramic brackets could increase stress at the concentrating area of the torque and tip when a controlled force is applied.(9,18,19) Fractures usually occur at the tie wings and the inner slot(19); thus, the bracket design of the tie wings and the inner slot is important for improving the fracture toughness of ceramic brackets.(19,20) CC bracket v1 was designed to have round corners and few sharp angles. However, the average tie-wing fracture resistance of CC bracket v1 was significantly less than that of the control group (41.74±5.34 and 89.48±15.93, respectively, $p<0.001$). Although this bracket design did not improve the Tie-wing FR, it could still withstand the fabrication process by preventing bracket wing fractures during disengagement from the mould.

Another important factor for the fracture resistance of a ceramic bracket is the grain size of the ceramic material. Larger grain sizes, especially those exceeding 5 µm, tend to reduce ceramic strength.(21-23) According to the SEM study, the commercial ceramic bracket was composed of grain sizes less than 10 µm, whereas the CC bracket v1 was composed of materials with grain sizes that exceeded 50 µm. This significant difference in grain size could contribute to the lower tie-wing fracture resistance of CC bracket v1 compared to that of the controls.

The fracture toughness of the bracket wing could be influenced by the thickness of the ceramic material. According to the critical load equation, the critical load varied with the square of the ceramic layer thickness(24-25), meaning that the strength of the bracket wing was affected by its dimensions. The wing of the CC bracket v1 was 0.2 mm thinner than that of the controls in all three dimensions. This difference in thickness could result in a reduced fracture resistance of the tie-wing of CC bracket v1. However, to our knowledge, no previous study has quantified an impact of different thickness on tie-wing fracture resistance. Therefore, it is suggested for future investigation.

Defects, such as voids and microcracks, occur during the custom manufacturing process(18,26), contributing to a reduction in the fracture resistance of CC bracket v1.(24,26-27) SEM analysis revealed the presence of pores in CC bracket v1, which could result in a lower tie-wing fracture resistance than that of commercial ceramic brackets.

When considering the ligating force to a bracket, the average Tie-wing FR of the CC bracket v1 (16.69±2.17 N) was still greater than the average elastomeric ligation force (3.6-5.3 N) reported by Nakhaei *et al.*(28) For the development of future versions of the CC bracket, in addition to the reduction of porosity, it might be necessary to decrease the grain size and increase the size of the wings.

Frictional resistance

Previous studies reported that the frictional resistance of ceramic brackets was greater than that of stainless-steel brackets. The frictional resistance of the slot of the bracket was caused by the high coefficient of friction of the ceramic material and increased by the rough surface condition.(29) To our knowledge, no study has reported clinically acceptable frictional resistance for fixed orthodontic brackets. Compared to previous studies(30-33) in which the frictional resistance of polycrystalline ceramic brackets (0.022”× 0.028”-slot) was tested with 0.019”×0.025” stainless steel wire and ligated with a clear elastomeric ring, the average static frictional resistance of CC bracket v1 (141.93±35 gf) was greater than that of Clarity Advance, 3M Unitek™ (86.83±25.4 gf), Signature, RMO™ (114.1±22.8 gf)(31) and Reflection, Ortho Technology™ (118.6±52.5 gf)(32) but less than that of Transcend series 6000, 3M Unitek™ (152.5±53.6 gf)(33) and Illusion plus, Ortho Organizers™ (230.45±0.21 gf).(30) The average frictional value of the CC bracket v1 was found to be the closest to those of the Transcend series 6000, 3M Unitek™. SEM revealed that the surface of CC bracket v1 exhibited greater irregularity than that of the controls, which is consistent with the findings of a previous study.(19) However, higher frictional resistance of the CC bracket v1 may affect the efficiency of tooth movement, further studies should be investigated in the future.

The manufacturer of the Clarity Advance reported that its bracket slot was coated with yttria-stabilized zirconia to reduce friction. In addition, a study reported that coating a slot with a silica layer could also reduce the frictional resistance.[34] These techniques can be used to improve the frictional resistance of CC bracket v1 in the future.

Conclusions

1. The CC bracket v1 was designed to incorporate the average curvature of the upper premolars of the Thai population onto the bracket base. It can be fabricated in an in-house laboratory using the injection-moulding technique and sintering.

2. The SBS of the CC bracket v1 was lower than that of the controls but clinically acceptable.

3. Although the Tie-wing FR of the CC bracket v1 was less than that of the controls, it was greater than the elastic ligature tying force to the bracket wings.

4. The frictional resistance of CC bracket v1 was greater than that of the controls but comparable to that of other commercial ceramic brackets.

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