Original Article

Torsional strength of computer-aided design/computer-aided manufacturing–fabricated esthetic orthodontic brackets

Najla Alrejaye[a]; Richard Pober[b]; Russell Giordano II[c]

ABSTRACT

Objective: To fabricate orthodontic brackets from esthetic materials and determine their fracture resistance during archwire torsion.

Materials and Methods: Computer-aided design/computer-aided manufacturing technology (Cerec inLab, Sirona) was used to mill brackets with a 0.018 × 0.025-inch slot. Materials used were Paradigm MZ100 and Lava Ultimate resin composite (3M ESPE), Mark II feldspathic porcelain (Vita Zahnfabrik), and In-Ceram YZ zirconia (Vita Zahnfabrik). Ten brackets of each material were subjected to torque by a 0.018 × 0.025-inch stainless steel archwire (G&H) using a specially designed apparatus. The average moments and degrees of torsion necessary to fracture the brackets were determined and compared with those of commercially available alumina brackets, Mystique MB (Dentsply GAC).

Results: The YZ brackets were statistically significantly stronger than any other tested material in their resistance to torsion ($P < .05$). The mean torques at failure ranged from 3467 g.mm for Mark II to 11,902 g.mm for YZ. The mean torsion angles at failure ranged from 15.3° to 40.9°.

Conclusion: Zirconia had the highest torsional strength among the tested esthetic brackets. Resistance of MZ100 and Lava Ultimate composite resin brackets to archwire torsion was comparable to commercially available alumina ceramic brackets. (*Angle Orthod.* 2017;87:125–130)

KEY WORDS: Orthodontic; Bracket; Torsional; Strength; Esthetic; Zirconia

INTRODUCTION

In the early 20th century, the first orthodontic bracket was introduced by Angle, and it was made of gold; ever since then, there has been development in bracket materials and design. Stainless steel brackets were developed and have become popular and used for decades. With the increased demand for esthetics, tooth-colored brackets were fabricated. The first esthetic bracket material was developed by Newman and his coworkers in the late 1960s. During the early 1970s, polycarbonate plastic brackets were manufactured and first made available commercially. Unfortunately, their acceptance by clinicians did not last long; they revealed a tendency to stain and discolor and had poor dimensional stability and creep deformation during torque. Although metal slots were placed in plastic brackets to overcome the problems of friction and poor dimensional stability, they are still not recommended in cases that need complicated orthodontic movements. Moreover, studies reported that the addition of ceramic and fiberglass fillers to polymers and the use of polyurethane did not improve torque stability.[1–5] In the mid-1980s, the first alumina ceramic brackets were introduced. Alumina brackets have shown greater stain and deformation resistance than the plastic ones. Commercially available ceramic brackets are either monocrystalline or polycrystalline alumina.[2] However, one of the major drawbacks of the

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available alumina brackets is their low fracture toughness and brittleness leading to occasional fracture during archwire ligation, torsion, or tipping.[6] Several studies have reported that the fracture of alumina ceramic brackets caused by torsional stresses has been a clinical problem facing orthodontists.[6–11] This may affect treatment efficiency by increasing the chairside time, causing patient discomfort, or subjecting the patient to the risk of swallowing bracket fragments or even aspiration.[9] Zirconia ceramic brackets were manufactured in Japan and Australia but have not been widely distributed in the market.[2] Unfortunately, there is limited published research on zirconia brackets.

An "ideal" orthodontic bracket should satisfy both mechanics and esthetics. It should be strong enough to withstand and transfer the applied stresses during orthodontic treatment, and it should not have an odd appearance or color that would draw attention. To the best of our knowledge, this is the first study to evaluate the fracture resistance of zirconia brackets to archwire torsion. The aim of this in vitro study was to fabricate esthetic orthodontic brackets from different materials and compare their fracture resistance during third-order archwire activation (torque) to those of conventional ceramic brackets.

MATERIALS AND METHODS

Computer-aided design/computer-aided manufacturing (CAD/CAM) technology (Cerec inLab, Sirona) was used to mill brackets with 0.018×0.025-inch slot. Materials used were Paradigm MZ100 and Lava Ultimate resin composite (3M ESPE, St Paul, Minn), Mark II feldspathic porcelain (Vita Zahnfabrik, Bad Säckingen, Germany), and In-Ceram YZ zirconia (Vita Zahnfabrik). Ten brackets of each material were subjected to torque by a 0.018×0.025-inch stainless steel orthodontic wire (G&H) using a specially designed apparatus. The average moments and degrees of torsion necessary to fracture the brackets were determined.

Fabrication of Orthodontic Brackets

The CEREC inLab CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany) was used to mill the brackets. However, it was not feasible to mill the bracket slot using CAD/CAM. Therefore, the bracket slot was first cut in each block before milling using a custom-made fixture and a diamond saw blade (Access Diamond, Inc, Georgetown, Calif) mounted in an IsoMet 5000 Precision Saw (Buehler Ltd, Lake Bluff, Ill). An appropriate blade thickness was chosen to obtain a desired slot width incisogingivally. For zirconia brackets, the slots were cut oversize to compensate for shrinkage during sintering. Adjusting the block axis vertically and horizontally in relation to the saw controlled the slot depth and position, respectively. After slot cutting, milling in Cerec inLab was done using Cerec 3D software. YZ brackets were sintered to full density in a Vita ZYrcomat furnace (Vita Zahnfabrik), specially programmed for sintering this kind of ceramic material at 1530°C. Ten brackets with a 0.018×0.025-inch slot of each material were produced.

Fracture Resistance of the Ceramic Brackets to Archwire Torsion (Torque Test)

Ten orthodontic brackets of each type were subjected to third-order archwire activation (torque) until failure; torque at failure values were then compared. Ten Mystique MB (Dentsply GAC Int'l, Bohemia, NY) polycrystalline alumina brackets were used as a control group and had similar dimensions to the milled brackets. All of the brackets were cemented to metal holders using resin cement (Multilink Automix, Ivoclar Vivadent, Schaan, Liechtenstein). Cementation was done following the manufacturer's instructions. The cement was allowed to set for at least 24 hours. The samples were kept in tap water at 37°C (Precision Economy Incubator, Precision Scientific, Winchester, Va) for 24 hours before testing.

Testing Apparatus and Testing Procedure

A specially designed apparatus was used to mimic rectangular archwire torquing (Figure 1). Brackets (A) cemented to metal holders (B) were positioned on a metal base (C) that had a crosshead (D) that could hold and twist an orthodontic wire (E) in rotational torque such that the applied torque would mimic the palatal root torquing effect of a rectangular wire. A string (F) was attached to a drum on the torque axis, and the other end of the string was attached to a 100-N load cell in a universal testing machine (model 4202; Instron, Canton, Mass). The Instron crosshead speed was 50 mm/min. Torque was applied to the brackets using a 0.018×0.025-inch stainless steel orthodontic wire (G&H Wire Company, Franklin, Ind), which was grasped about 6 mm lateral to the center of each bracket at both ends by two arms projecting from a rotating cylinder. This distance is considered to be an average interbracket distance (clinically).[8,11] The wire was aligned parallel with the slot to eliminate or minimize any effect from the existing torque or angulation in the bracket slot, thereby having 0° torque and 0° angulation as a starting point. Round (Open Ring) rubber bands (Alliance Rubber Company, Franklin, Ky) were used to hold the wire in the bracket slot while testing. The force (g) and displacement (mm)

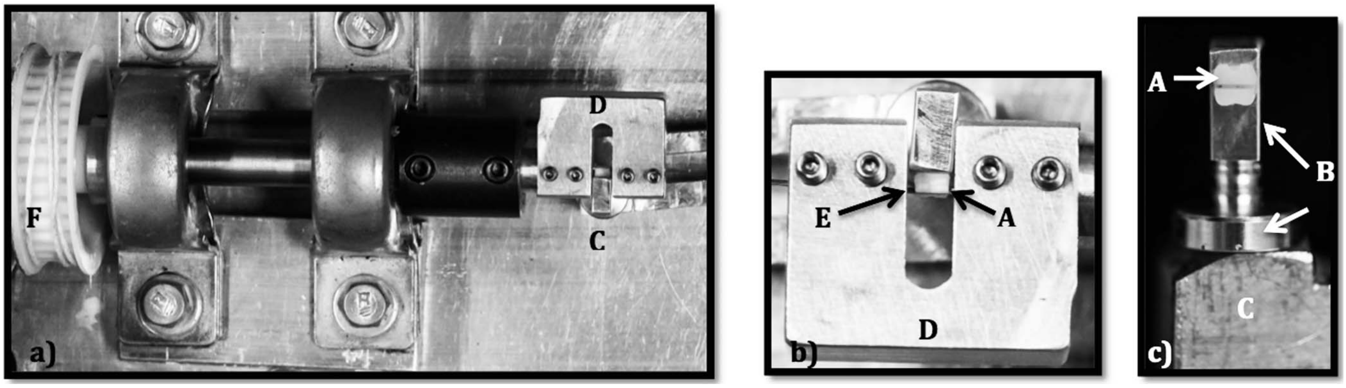

Figure 1. (a) Torque test apparatus made of a cross-head (D) connected to a drum with a string (F) attached to the Instron machine. (b) Top view of the wire (E) engaged in the bracket (A). (c) Bracket cemented on a metal holder (B), which is positioned on a metal base (C).

at failure were recorded along with the fracture locations.

Statistical Analysis

One-way analysis of variance and Tukey-Kramer honestly significant difference were performed for the data set using JMP 10 software (SAS Institute Inc, Cary, NC) at a .05 level of significance.

RESULTS

The torque value required to fracture each bracket was calculated by multiplying the fracture load (g) by the pulley radius, which was 25 mm. The torque angle at failure was calculated by converting the linear displacement of the string (in millimeters), needed to twist the wire until failure, to rotational motion (in degrees). The mean torque values and degrees of torsion necessary to fracture the brackets were determined and compared (Table 1). Overall, there were statistically significant differences among the tested brackets ($P < .0001$). YZ brackets were statistically significantly stronger than any other tested material ($P < .05$), while MKII showed the lowest resistance to fracture, which was statistically significant ($P < .05$). However, no statistically significant difference was detected when Mystique was compared with MZ100 and Lava Ultimate ($P > .05$). The mean torque angle at failure ranged from 15° for Mark II to 41° for YZ.

Table 1. Mean Torque Values in Gram-Millimeter and Torsion Angles in Degrees at Failure With Standard Deviations for Each Group[a]

Group	Torque at Failure (g.mm)	Significant Difference	Torsion Angle at Failure (°)
YZ zirconia	11,902 ± 1976	A	40.9 ± 6
MZ100 resin composite	9107 ± 1637	B	29.2 ± 5
Mystique alumina	8433 ± 1346	B, C	30.8 ± 5
Lava Ultimate resin composite	7032 ± 1837	C	26.4 ± 5
Mark II porcelain	3467 ± 669	D	15.3 ± 3

[a] Groups with different letters are significantly different at $\alpha = .05$.

Mode of Failure

Fracture locations for the tested brackets are summarized in Table 2. Ninety-six percent of the tested brackets showed fracture at either the incisal or gingival halves or both, with the incisal fracture being the dominant one. All YZ brackets had fractured at the incisal half, while other materials showed some variation in the fracture locations (Figure 2). Most Mystique brackets showed complete separation of the broken half rather than chipping, as shown in Figure 3.

DISCUSSION

The results showed that the mean torque at failure ranged from 3467 g.mm for Mark II to 11,902 g.mm for YZ. This range is well above the recommended torque values for a maxillary central incisor, which were reported by several authors in the literature and varied from 1035 to 2373 g.mm.[12–16] However, tipping and torque forces could be combined during orthodontic treatment exerting larger stresses, and sometimes clinicians may need larger forces than those reported to overcome other forces they are using. In addition, direct trauma could also cause greater forces, which may lead to bracket fracture. Moreover, surface cracks or fatigue may lower bracket strength, leading to failure at loads lower than those reported in this study. The brittle fracture behavior of ceramic brackets was investigated, and studies have shown that their fracture resistance could be significantly reduced by surface cracks and flaws. Cracks may propagate easily in ceramic materials because of a lack of plastic deformation.[7,17]

Statistically significant differences among the tested brackets were detected ($P < .0001$). YZ brackets had

Table 2. Mode of Failure for Each Group (n = 10 per Group)[a]

Major fracture location*		YZ	Mystique	MZ100	Lava Ultimate	Mark II	Total
Incisal half		10	—	5	7	6	28
Gingival half		—	3	4	2	4	13
Incisal + gingival halves		—	7	—	—	—	7
Incisal half + mesio-gingival wing		—	—	1	—	—	1
Disto-incisal wing		—	—	—	1	—	1

[a] Shaded area indicates the major fracture locations.

statistically significantly higher torsional strength than any other group and caused severe wire distortion; this high level of stress would not normally be reached during treatment. This is not surprising; studies have shown that zirconia is the strongest dental ceramic material so far. It has superior flexural strength and fracture toughness compared with other dental ceramics (Table 3).[25,26] Milling and slot-cutting procedures probably caused flaws and internal stresses in the fabricated brackets that were probably relieved during sintering of YZ brackets in contrast to MZ100, Lava Ultimate, and Mark II that were tested directly after milling without further treatment. Although this might have contributed to lower strength values recorded for the latter three groups, it might not be significant.

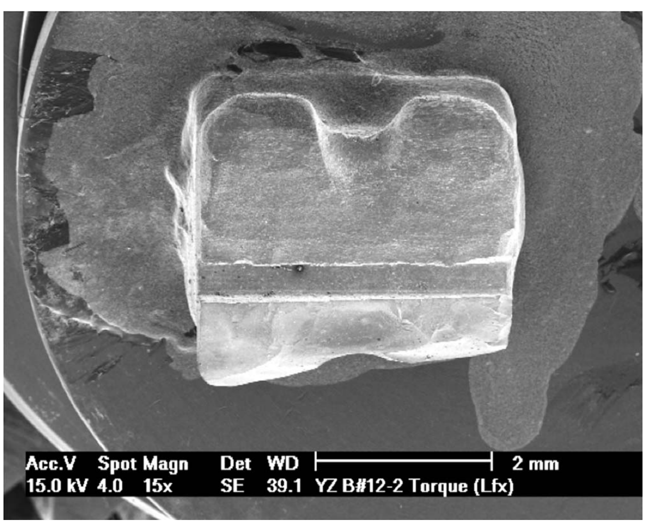

Figure 2. Scanning electron micrograph showing an angled front view of a YZ bracket with incisal half failure, at 15×.

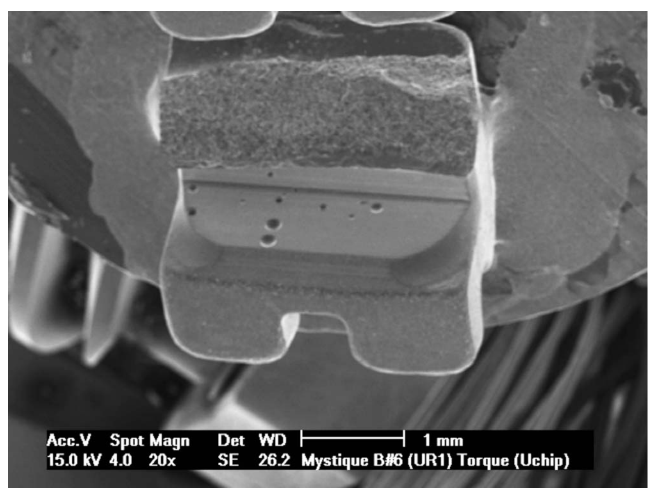

Figure 3. Scanning electron micrograph showing complete separation of the gingival half of a Mystique bracket at 20×. Dark spots/semispherical areas at the slot walls were noticed, which may indicate the presence of porosities in the silica slot lining.

Table 3. Flexure Strength, Elastic Modulus, and Fracture Toughness Comparison

Material	Composition	Flexural Strength (MPa)	Modulus of Elasticity (GPa)	Fracture Toughness (MPa m)
Mark II[18]	Feldspathic porcelain	154 ± 15	63 ± 0.5	1.7 ± 0.1
MZ100[19,20]	Resin-based composite	145 ± 17	12	1.3 ± 0.1
Lava Ultimate[21]	Resin-based composite	204 ± 19	12.77 ± 0.99	2.02 ± 0.15
Polycrystalline Alumina (99.9% purity and sintered)[22]	Alumina	280[22]	390[22]	3–5.3[7,23]
Vita In-Ceram YZ[24]	3 mol% yttria-stabilized zirconia	>900	210	5.9

MZ100 brackets were significantly stronger than Mark II. This is in agreement with the findings of a recent study by Ziadeh et al.[27] in which MZ100 and Mark II brackets were fabricated using Cerec inLab and evaluated during torque; however, the actual mean values were different than those obtained in the present study. The mean torsional strengths reported by Ziadeh et al.[27] was 3244.8 g.mm for MZ100 and 2194 g.mm for Mark II. The difference may be due to different slot and wire size used by those investigators, which was 0.021 × 0.025-inch wire in a 0.022-inch slot. Although the flexural strength of alumina was reported to be almost twice the strength of MZ100 (Table 3), the present study revealed no statistically significant difference between the torsional strength of MZ100 resin composite and Mystique alumina when tested in the design of an orthodontic bracket (Table 1). Cutting or processing procedures done to make the brackets could be a factor that contributed to the relative decrease in alumina strength. Moreover, a previous study by Addiego[28] indicated that the mean torsional fracture strength of MZ100 was statistically significantly lower than those of commercial alumina brackets. This contradicts the findings of the present study. This could be caused by factors related to differences in the study design such as the method of bracket fabrication; Addiego[28] used the Celay system and small diamond disks for bracket and slot preparation. Several authors investigated the fracture strength of commercially available alumina brackets during archwire torsion and reported a range of 3706 to 9316 g.mm.[8,9,11] The mean strength of Mystique alumina brackets recorded in the present study was 8,433 g.mm, which is closer to the mean strength reported by Aknin et al.[9] for Allure IV polycrystalline alumina brackets that was 8382 g.mm; on the contrary, it is more than twice the mean reported for alumina brackets tested by Nishio et al.,[11] which was 3528 g.mm for Clarity alumina brackets with a stainless steel slot. Moreover, MZ100 and Lava Ultimate composite brackets evaluated in this study had a mean strength of 9107 g.mm and 7032 g.mm, respectively, and these are much higher than the mean strengths of the polycarbonate brackets tested by Nishio et al.,[11] which were 1463.6 g.mm for conventional polycarbonate brackets and 2142 g.mm for polycarbonate brackets reinforced with a stainless steel slot. Comparisons with previous studies may not be relevant due to several factors, such as differences in brackets size and design, manufacturing process, slot and wire sizes, experiment design and testing apparatus, or different tested materials. For instance, the size of the bracket slot and the wire used by Nishio et al. was 0.022 × 0.028 inches and 0.021 × 0.025 inches, respectively; however, in the present study, size 0.018 × 0.025 inches was tested for both the slot and the wire to minimize the gap between the wire and the slot. Besides the wire and slot size, the type of bracket material and design are also important variables that probably contributed to having different results.

In this study, fracture at the incisal half was the dominant mode of failure followed by the gingival half. These findings are in agreement with previous studies.[8,9,11,29] Ghosh et al.[29] studied the stress distribution pattern in commercially available ceramic brackets and showed that during palatal torque of maxillary incisors, stresses were mainly concentrated at the points of force application, which are the junction between the slot gingival wall and the bracket frontal surface and the junction between the slot incisal wall and the slot base. Previous studies assessed the fracture locations of maxillary incisor ceramic brackets subjected to palatal root torque and found that the complete fracture of the incisal half was the dominant mode of failure, followed by the gingival half fracture, where stresses probably dissipated over a greater surface area.[8,9,11] All YZ brackets tested in the present study had incisal half fracture, which suggests that they may have more consistent stress distribution and consequently mode of failure. Mystique brackets had a prescription built in the slot (torque = +18, angulation = +5); however, the milled brackets had no prescription built in. This difference in design could be one of the factors that contributed to variation in mode of failure. The range of degrees of torque at failure was from 15° for Mark II to 50° for YZ.

More studies are recommended to evaluate the fracture resistance of these esthetic brackets to archwire tipping, determine the fracture strength of these brackets tie wings when subjected to tension, investigate the fatigue effect on these brackets over time, and verify their behavior clinically since many factors are difficult to simulate in vitro, such as biological tooth movement and bone response during load application and oral cavity temperature and pH changes.

CONCLUSIONS

Within the limitations of this in vitro study:

- Zirconia had the highest torsional strength among the tested esthetic brackets.
- Resistance of MZ100 and Lava Ultimate composite resin brackets to archwire torsion was comparable with commercially available alumina ceramic brackets.

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