ORIGINAL ARTICLE

Evaluation of esthetic brackets' resistance to torsional forces from the archwire

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Introduction: The aim of this study was to evaluate the resistance to deformation or fracture of esthetic brackets produced by archwire torsion. **Methods:** Six types of maxillary right central incisor brackets were analyzed: traditional ceramic brackets (cer); ceramic brackets reinforced with a stainless steel slot (cer/ss); ceramic brackets reinforced with a gold slot (cer/gold); traditional polycarbonate brackets (poly); polycarbonate brackets reinforced with a stainless steel slot (poly/ss); and polycarbonate brackets reinforced with ceramic fillers and a stainless steel slot (poly/cer/ss). Stainless steel wire segments were used, and the testing instrument (Emic DL 10000, São José do Rio Preto, PR, Brazil) was moved at a rate of 1 inch per minute to generate the wire torsion. **Results:** The brackets showed deformation or fracture resistance values (gf·mm) in decreasing order as follows: cer/ss (3528.1 $\pm$ 516.6), cer/gold (2858.7 $\pm$ 611.6), cer (2424.0 $\pm$ 352.1), poly/cer/ss (2279.5 $\pm$ 174.5), poly/ss (2142.0 $\pm$ 275.7), and poly (1463.6 $\pm$ 193.3). The cer/ss ceramic brackets showed the greatest statistically significant ($P < 0.01$) values of resistance to fracture, and the poly brackets had the lowest statistically significant ($P < 0.01$) values of resistance to deformation. The cer brackets showed no significant differences ($P > 0.01$) from the cer/gold, the poly/cer/ss, and the poly/ss brackets. **Conclusions:** This suggested that the stainless steel slot might enhance resistance to deformation or fracture, although gold slots and ceramic fillers are ineffective for reinforcing esthetic brackets. (Am J Orthod Dentofacial Orthop 2009;135:42-8)

Since the number of adults seeking orthodontic treatment has increased, orthodontists might have to use more esthetic appliances for these patients.[1] The development of orthodontic appliances and materials with acceptable esthetics for the patient and optimal technical performance for the orthodontist has been an extremely essential goal.[2,3]

Until now, 2 major esthetic brackets, ceramic and polycarbonate, have been developed. However, from 1986 to 1990, the use of ceramic brackets by American orthodontists increased from 5.6% to 88.2% (mean), whereas the use of polycarbonate brackets decreased from 57.6% to 24.3%.[4] The possible explanation for this might be that polycarbonate brackets have demonstrated unsatisfactory results caused by their inferior physical and mechanical properties. Poor resistance to deformation and discoloration can reduce the incorporation of torque essential for tooth movement[5] and jeopardize esthetic satisfaction.[2,6-8] Although ceramic brackets have low fracture toughness,[3,8-14] these attachments were developed to replace polycarbonate brackets because they are not susceptible to deformation and staining.[2,6,7,15-17] However, the fracture toughness of ceramic brackets need to be improved. Although elongation (strain is the amount of deformation per inch) for sapphire is less than 1% when it finally fails, the strain of stainless steel at failure is approximately 20%.[11]

Brackets are subjected to various mechanical forces during orthodontic treatment. Therefore, esthetic brackets can deform or break during placement of a rectangular archwire into the bracket slot, during ligation of an archwire to the bracket, and during the transmission of torque and tip from archwire to bracket.[2] Torque moments commonly applied to the anterior teeth are especially likely to cause bracket fracture.[9,10,15,18]

To enhance fracture toughness during torque incorporation, ceramic brackets with the slot covered by

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Table I. Description of esthetic brackets

Bracket	*Characteristics*	*Angulation (°)*		*Commercial name (manufacturer)*
		Tip	*Torque*	
Ceramic	Ceramic slot (cer)	0	0	Transcend 6000 (3M Unitek, Monrovia, Calif)
	Stainless steel slot (cer/ss)	0	0	Clarity (3M Unitek)
	Gold slot (cer/gold)	+5	+12	Luxi II (Rocky Mountain Orthodontics, Denver, Colo)
Polycarbonate	Polycarbonate slot (poly)	+5	+12	Blonde (GAC International, Bohemia, NY)
	Stainless steel slot (poly/ss)	+5	+12	Elation (GAC)
	Ceramic filler+ stainless steel slot (poly/cer/ss)	+5	+14	Spirit MB (Ormco/A Company, San Diego, Calif)

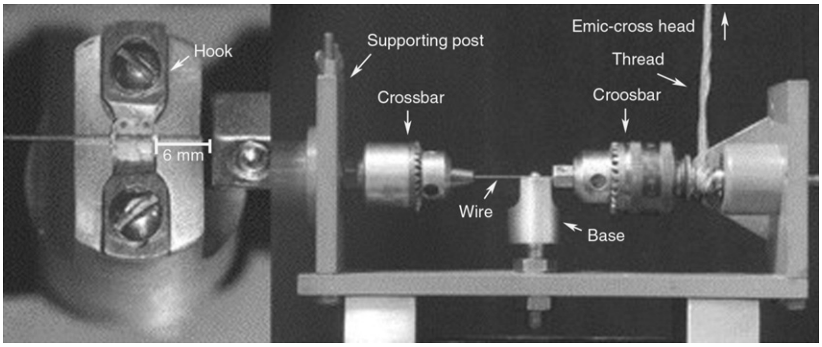

Fig 1. Testing apparatus to apply torsion load (*right*) and upper view of the base accessory to hold the bracket (*left*).

stainless steel and gold were developed, although there is not enough research to evaluate their toughness against fracture.[19] Recently, polycarbonate brackets have also been reinforced with a ceramic filler and stainless steel slots. It is thus hypothesized that the ceramic filler would prevent the brackets from staining and improve the strength of polycarbonate brackets[8] and that the metal slot would prevent distortion during torque force application and reduce bracket-wire friction.[6,20,21] Nevertheless, comparisons of fracture or deformation toughness between ceramic and polycarbonate brackets have not been conducted. Therefore, insight into the resistance properties of esthetic brackets might verify the efficacy of their modifications for resistance to fracture and deformation.

The purposes of this study were to compare esthetic brackets' resistance to deformation or fracture from archwire torsion load and to analyze the correlation between bracket dimensions and resistance to deformation or fracture. The bracket areas with higher incidences of fracture were also registered.

MATERIAL AND METHODS

Ten brackets for the maxillary right central incisor (.022 × .028 in) from 6 types of esthetic brackets were used: 3 types of ceramic brackets (traditional [cer], reinforced with stainless steel slot [cer/ss], and reinforced with gold slot [cer/gold]) and 3 types of polycarbonate brackets (traditional [poly], reinforced with stainless steel slot [poly/ss], and reinforced with ceramic fillers and stainless steel slot [poly/cer/ss]). All brackets, excluding the cer and cer/ss samples, had built-in torque. Sixty stainless steel archwire segments of .021 × .025 in and 5.0 cm in length (3M Unitek, Monrovia, Calif) were also used in this study (Table I).

Three types of bases were constructed with different tip and torque angulations: 0° tip/0° torque, +5° tip/+12° torque, and +5° tip/+14° torque. The purposes of the bases with varying angulations were to compensate for the different built-in angles between straight wire and standard edgewise, and to permit a passive position between slot and wire. The brackets were fixed onto the respective bases with instantaneous glue (Super Bonder, Loctite Brasil, São Paulo, Brazil) with hooks to hold the brackets' base (Fig 1).

Supporting posts were used to mount a crossbar that could hold and twist the wire without displacement in another direction. A thread was fastened to the crossbar for twisting the wire. The opposite crossbar held the other end of the wire in place and rotated simultaneously in the same direction. The end of the thread was attached to the load cell on top of the testing machine (Emic DL 10000, São José do Rio Preto, PR, Brazil) connected to a load cell of 20N and standardized with a crosshead speed of 1 inch per minute.[9,10] The crossbar was hemi-sectioned and notched on the end to permit the archwire to fit only 1 way and to be centered each time. The bracket was placed 6 mm from the end of the crossbar wire holder to the mesial side of the bracket (Fig 1). This distance was standardized because it is considered to be an average interbracket distance between the maxillary incisors.[6,9,22-24] The other end of the wire remained 24 mm from the tip of the opposite crossbar wire holder. The stainless steel wire was ligated onto the brackets with elastomeric ties (Morelli, Sorocaba, SP, Brazil) and a mathieu-style ligature-tying pliers.

Before the mechanical test, the dimensions of all brackets were measured (width, height, and slot depth) with a projector profile. The thickness and the width of the wire were also measured by a digital pachymeter at 3 points. One examiner (C. N.) made the measurements twice 2 hours apart.

Each bracket-wire combination was randomly selected. Before the measurements, each combination was cleaned with 95% ethanol to remove surface contamination and dried with air spray. The mechanical test was executed with gradual torsion applied to the archwire until the bracket deformed or fractured.

The amount of force (gf) exerted by the thread was recorded. The highest point on the recording chart was regarded as the moment of bracket fracture or deformation. To obtain the torque in gram-millimeters, the force was multiplied by the radius of the crossbar (4 mm), according to the following equation: $T = F \times r$, where T = torque, F = force obtained, and r = radius of the crossbar.

The data were stored in a personal computer and subjected to statistical analyses, such as th Snedecor F-test, the Bonferroni adjustment, the Student t test ($P < 0.01$), and the linear correlation analysis ($P < 0.05$).

After the mechanical test, all brackets were evaluated for the location of the deformation and fracture. The polycarbonate brackets were subjected to the projector profile to remeasure the dimensions and analyze the deformation. One specimen from each of the 6 bracket types was evaluated with a scanning electronic micrograph for the slot's adjustment to the bracket surface.

RESULTS

The maximum force (gf) recorded by the load cell was related to the moment of the ceramic bracket fracture and to the maximum elastic deformation of the polycarbonate brackets. According to the mean value (gf·mm), the esthetic brackets had increasing deformation or fracture resistance values in the following order (Fig 2): poly, poly/ss, poly/cer/ss, cer, cer/gold, and cer/ss.

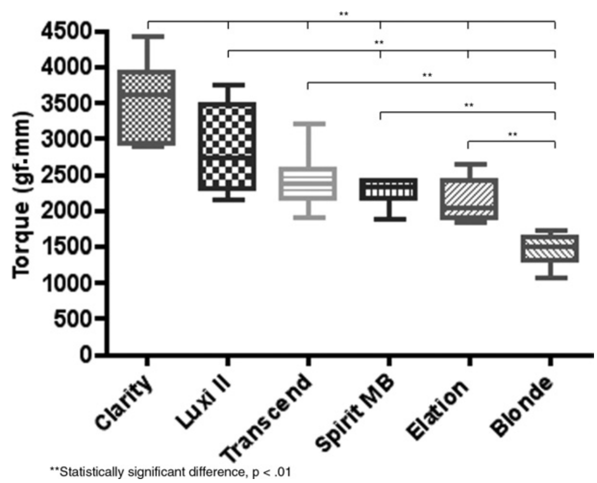

Fig 2. Statistical description of resistance force values (gf.mm): Clarity (cer/ss), Luxi II (cer/gold), Transcend 6000 (cer), Spirit MB (poly/cer/ss), Elation (poly/ss), and Blonde (poly).

The cer/ss bracket had the greatest resistance value (3528.1 gf·mm) with statistical significance ($P < 0.01$) compared with the other esthetic brackets. This means that the cer/ss force value was 45.54% greater than the ceramic bracket without the reinforced slot (cer = 2424.0 gf·mm). In contrast, poly brackets had the smallest resistance force, which was statistically significant ($P < 0.01$).

However, no statistically significant differences were found ($P > 0.01$) between the cer and cer/gold, the cer and poly/ss, the cer and poly/cer/ss, and the poly/cer/ss and poly/ss. Figure 2 shows 3 levels of resistance force: low (1463.6 gf·mm for the poly), intermediate (2142.0-2424.0 gf·mm for the poly/ss, poly/cer/ss, and cer), and high (2858.7-3528.1 gf·mm for the cer/gold and cer/ss) (Fig 2).

The width, height, and depth of the bracket slot were measured twice to verify whether the dimensions could affect the resistance to deformation or fracture under torsion force. The error of measurement for the same investigator showed no deviation from zero at the .05 level of statistical significance. Although all brackets had similar dimensions, the cer/gold and the poly/ss brackets were wider, the polycarbonate brackets were slightly deeper than the ceramic ones, and the cer bracket was significantly narrower statistically ($P < 0.05$) (Table II).

Table II. Correlation coefficient between the resistance force values and the dimensions of the brackets slots

Bracket	*Dimension (average mm)*	*Resistance (gf · mm)*	*t*	P *value**
Transcend (cer)	Width (3.574)	−0.64	−2.38	0.045
	Height (0.568)	0.44	1.38	0.204
	Slot depth (0.716)	0.36	1.11	0.299
Clarity (cer/ss)	Width (3.581)	0.04	0.12	0.905
	Height (0.568)	−0.32	−0.95	0.371
	Slot depth (0.716)	0.39	1.21	0.260
Luxi II (cer/gold)	Width (3.656)	−0.12	−0.36	0.731
	Height (0.568)	−0.03	−0.09	0.932
	Slot depth (0.711)	0.14	0.41	0.695
Blonde (poly)	Width (3.430)	0.46	1.46	0.182
	Height (0.586)	−0.60	−2.14	0.064
	Slot depth (0.783)	−0.17	−0.48	0.642
Spirit MB (poly/cer/gold)	Width (3.448)	0.25	0.72	0.490
	Height (0.583)	0.05	0.15	0.883
	Slot depth (0.783)	−0.23	−0.66	0.529
Elation (poly/ss)	Total width (3.746)	0.11	0.33	0.750
	Slot width (2.557)	−0.08	−0.25	0.810
	Height (0.567)	0.39	1.19	0.267
	Slot depth (0.769)	−0.59	−2.05	0.075

*Statistically significant difference, $P < 0.05$.

In relation to the wires, all measurement points were uniform and had the same values of .021 × .025 in. This size of stainless steel wire was selected to fill up the slots' size of .022 × .028 in and to enhance the effect of torque.

The major fracture area of the ceramic brackets was at the incisal wing: cer, 70%; cer/ss, 40%; and cer/gold, 100% (Table III). These findings agree with those of previous studies.[9,10] It was impossible to evaluate the areas of the polycarbonate brackets' deformation because they had reversible distortions.

Table III. Areas of major fracture incidence in the ceramic brackets

Fracture areas	*Transcend (cer)*	*Clarity (cer/ss)*	*Luxi II (cer/gold)*
Cervical right wing	—	20%	—
Cervical left wing	—	—	—
Incisal right wing	—	20%	—
Incisal left wing	—	—	—
Cervical right/left wing (total)	30%	20%	—
Incisal right/left wing (total)	70%	40%	100%

DISCUSSION

This study was designed to evaluate the mechanical resistance to orthodontic torquing moments of various commercially available esthetic brackets. Ceramic and polycarbonate brackets have shown relatively large variations of resistance to orthodontic forces in clinical use. In addition, scant information is available about the comparison of the mechanical resistance of these brackets. To our knowledge, this is the first study in which the resistance to deformation and fracture of ceramic and polycarbonate brackets has been evaluated mutually.

All mechanical tests were performed under similar conditions to clinical use. The wire was twisted in the direction of the brackets' cervical wings, simulating the lingual torque of a dental root. In a finite element study, when lingual root torque was applied, it was observed that the stress tended to concentrate at the bracket's incisal base and irradiate to the incisal wings, making the ceramic bracket more fragile.[18] However, the stress at the cervical wing seems to be dissipated over a larger area, decreasing the incidence of fracture in this area.[18]

In our mechanical test, we verified that ceramic brackets fractured, whereas polycarbonate brackets deformed. From the polycarbonate brackets, it was also noticed that the wire rotated inside the bracket slot. The deformation in the polycarbonate brackets seemed to be reversible, since they returned to the original shape after unloading and had the same dimensions before and after mechanical stress.[23] This indicates that polycarbonate brackets could dissipate the torquing moment as heat or strain energy and have greater recovery after unloading. According to Feldner et al,[6] approximately 12% to 15% of torquing moment was reduced by the creep characteristics of the polycarbonate material. Therefore, it is suggested that orthodontists should apply additional torque to the archwire to obtain the expected moment when using a polycarbonate bracket.[6,21,25]

In general, ceramic brackets are well known to have higher resistance to deformation or fracture than polycarbonate brackets. This study confirmed that ceramic is a resistant and rigid material, whereas plastic is more flexible and resilient.

In a clinical situation, the torquing moment transferred from the wire to the maxillary central incisor was 1035 to 2373 gf·mm.[26-29] Therefore, our results indicated that all esthetic brackets, except the poly, have enough resistance to deformation or fracture to incorporate torque to the maxillary central incisor. Nevertheless, we demonstrated that esthetic brackets have less fracture and deformation toughness than do metal brackets.[10,11] Consequently, orthodontists must handle these attachments carefully and apply gradual and continuous moments when torque is incorporated.

Of the reinforcing methods for esthetic brackets, the cer/gold was not as efficient at enhancing the resistance to fracture. All brackets reinforced with a stainless steel slot showed higher resistance to deformation and fracture than those without a stainless steel slot. These results agree with other studies.[6,17,21,25,30,31] All polycarbonate brackets with stainless steel slots showed the same resistance to deformation or fracture as the ceramic brackets. This can be explained by the greater malleability of gold, which seems to be more flexible than stainless steel.

From the findings of the scanning electronic micrograph, the attachment of the gold slot (Fig 3) to the bracket was better adjusted than the stainless steel slot (Fig 4). Despite that, the sealant material between the gold slot and bracket (Fig 3, *d*) seemed to be thicker than that between the stainless steel slot and the bracket (Fig 4, *d*). This thick sealant material might affect the slot's rigidity and the resistance to the fracture.

The ceramic filler in the polycarbonate brackets had been reported as another variable that could influence their resistance to deformation. In this study, however, the poly/ss and poly/cer/ss showed no significant difference. This implies that the ceramic filler did not enhance the brackets (Fig 2) as found in previous studies.[6,21,25]

When the relationship between bracket dimension and resistance to deformation and fracture was evaluated by the linear correlation analysis, there was no correlation between these 2 variables. However, only the cer brackets showed a statistically significant correlation ($P < 0.05$) between width and resistance. As the bracket became wider, the resistance values became lower (Table II). Nevertheless, we believe that the lower resistance of the cer brackets seems to be related to the absence of the reinforced slot rather than the size variation, since the difference between the brackets' widths was not so evident.

To evaluate the resistance to deformation and fracture of the brackets under various orthodontic forces, more studies should be conducted. Many intraoral

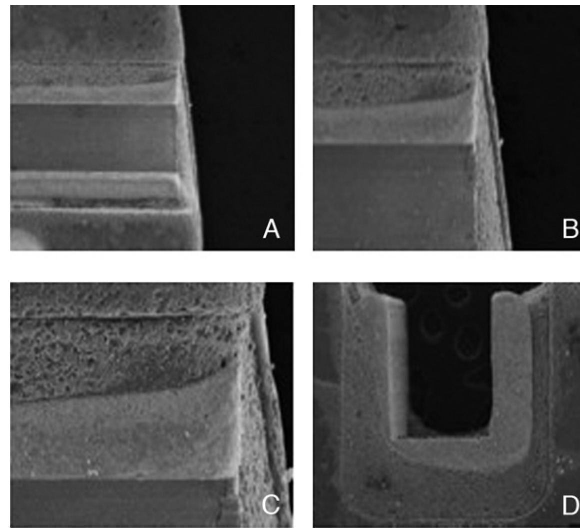

Fig 3. Magnification of the adhesion of the gold slot on the surface of the Luxi II bracket (cer/gold) (frontal view): **A,** 50 times; **B,** 100 times; **C,** 200 times; and **D** (profile view), 80 times.

Fig 4. Magnification of the adhesion of the stainless steel slot on the surface of the Clarity bracket (cer/ss) (frontal view): **A,** 50 times; **B,** 100 times; **C,** 200 times; and **D** (profile view), 80 times.

factors can affect the bracket's resistance: corrosion, chewing, plaque, saliva, bone density, tooth number, root surface area, anatomic configuration, and occlusion. Furthermore, the influence of others factors such as pH, enzymes, and oral microorganisms on the esthetic brackets' stability is still unknown.[21] Also, the effect of esthetic bracket deformation or fracture on adjacent teeth is another issue yet to be evaluated.

CONCLUSIONS

1. Ceramic brackets showed higher resistance force values than polycarbonate brackets. The cer/ss demonstrated the highest resistance to fracture, followed, in decreasing order, by cer/gold and cer brackets. Of the polycarbonate brackets, the poly/cer/ss had the highet resistance to deformation followed by poly/ss and poly.
2. The cer brackets did not have statistically significant ($P > 0.01$) resistance force values when compared with cer/gold, poly/cer/ss, and poly/ss brackets. The stainless steel slot seems to reinforce the resistance to deformation or fracture, but this was not demonstrated by the gold slot. Also, the inclusion of a ceramic filler in the polycarbonate brackets does not appear to enhance resistance to deformation.
3. The area of major fracture incidence in the ceramic brackets was at the incisal wing. It was not possible to evaluate the areas of the polycarbonate brackets' deformation because they had reversible distortions.
4. The size of esthetic brackets did not influence the results of resistance force values. The lower resistance fracture values of cer brackets seemed to be associated with the absence of the reinforce slot rather than to the size variation.

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