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Original Article

Comparison of Tie Wing Fracture Resistance of Differing Ceramic Brackets

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Main Points

- This study found significant differences concerning tie wing facture resistance.
- 3M Clarity brackets had the highest resistance to tie wing fracture.
- Dentsply Ovation S had the lowest resistance to tie wing fracture.

ABSTRACT

Objective: The aim of this study was to compare the tie wing fracture resistance of 4 different manufacturers' ceramic brackets currently on the market.

Methods: The tie wings of ceramic brackets from 4 manufacturers were tested with 10 samples in each group. The brackets were Ormco Symetri, 3M Clarity, American Radiance Plus, and Dentsply Ovation S. The brackets were mounted and fixed in a universal testing machine. A stainless steel ligature wire was looped around a tie wing and the mean tensile strength was both tested and recorded.

Results: There was a significant overall difference in tensile strength among the 4 groups ($P < .0001$) with the 3M Clarity brackets having the highest MPa. When the groups were compared to each other, they also showed a significant difference in mean tensile strength with the exception being the American Radiance Plus and Ormco Symetri brackets.

Conclusion: Test results concluded that the 3M Clarity brackets had the highest resistance to tie wing fracture, while the Dentsply Ovation S brackets had the lowest resistance.

Keywords: Fracture resistance, ceramic orthodontic brackets, tie wing fracture, monocrystalline, polycrystalline

INTRODUCTION

As interest in orthodontic treatment has increased over recent years, the desire for esthetic treatment options has also increased.[1] Many options have arisen including the use of clear aligner therapy, lingual brackets, and ceramic brackets as alternatives to the traditional metal bracket. It is not uncommon for many patients to request ceramic brackets due to the advantage of being white or clear and blending with the surface of the enamel.[2] Although these brackets are more esthetic, they do have a higher susceptibility and frequency of fracture, especially the tie wings, as compared to traditional metal brackets as ceramic material lacks ductility.[1,2] Research has been conducted testing ceramic bracket fracture strength using a variety of forces: tipping, torsion, shear, and impact.[2,3-9] A frequent area of fracture of ceramic brackets occurs at the tie wing or at the junction of the tie wing and base.[2,10] When a tie wing fractures, the bracket needs to be replaced as it creates difficulties in ligating the archwire, fully engaging the archwire in the slot which affects the expression of the bracket prescription, and the ability to attach auxiliaries such as powerchain or elastics. In addition, a bracket

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with a tie wing fracture has a higher likelihood of a fracture of the bracket which also necessitates bracket replacement.[11] The tie wing fracture and the additional bracket fracture also pose an aspiration hazard for the patient.[12] Because of these issues, it is important to test the fracture resistance and tensile strength of tie wings of these bracket types.[2]

Ceramic brackets are manufactured in either a monocrystalline or polycrystalline state and the manufacturing process may play a role in the varying degrees of resistance to fracture.[13] Monocrystalline (single crystal) brackets are manufactured using aluminum oxide (Al_2O_3) that is heated which causes the particles to melt. The Al_2O_3 mass is then cooled, allowing for controlled crystallization forming 1 single crystal. The brackets are then milled from this crystal using diamond cutting tools. Once formed, they are further heat treated to remove any impurities.[13,14] This process is more expensive than forming a polycrystalline bracket.[13] Producing brackets in this manner results in a decreased likelihood of fracture due to fewer impurities but does not eliminate fracture altogether because the milling process can induce stress which results in brackets that are more prone to fracture.[14]

Polycrystalline brackets are typically produced by a ceramic injection molding technique. In this technique, the Al_2O_3 particles are mixed with a binder and the mixture is forced into a bracket mold through pressurization. Following this, a sintering process occurs in which the mold is heated, not melted, and the binder burns out. The bracket is then machined and heat treated to remove surface imperfections and stresses that occur during the cutting process.[13] The advantage to producing brackets in this manner is that they can be produced quickly, more cheaply, and in bulk.[14,15] However, manufacturing brackets in this manner produces defects at grain boundaries, inducing impurities, which increases its propensity to fracturing.[14] When cracks do occur in polycrystalline brackets, the propagation of the crack occurs more slowly due to the grain boundaries as opposed to a monocrystalline bracket in which the fracture occurs all at once.[16]

In addition to the propensity to fracture, an orthodontist may also consider the translucency of the bracket. As a result of the different manufacturing processes, monocrystalline and polycrystalline brackets have different optical properties. A single-crystal bracket is more translucent as it has less tendency to refract light because of fewer impurities introduced during its manufacturing process. The polycrystalline brackets, with more impurities, appear more opaque.[14]

A PubMed search utilizing "ceramic bracket tie-wing fracture" yielded only 3 articles published since 2005. Using ceramic brackets with a higher tie wing resistance to fracture benefits both the patient and the treating orthodontist. A bracket with a fractured tie wing would lead to an increase in the chair time in order to replace the bracket, an increase in time away from work or school, a potential increase in total treatment time for the patient, a potential increase in the risk of enamel removal from the tooth surface each time a bracket needs to be replaced, and the additional expense of replacing a broken bracket. According to Dr. Sondhi in 2000, in a best-case scenario, a single-bond failure can result in a 20-30 minute loss in chair time and a cost of \$70-\$80 to the practice.[17] That cost would be even greater today.

This laboratory study sought to determine the tie wing fracture resistance of 4 different manufacturers' ceramic brackets when a force is placed directly under the tie wing. The results of this study will add to the data regarding the tie wing failure of ceramic brackets allowing orthodontists to make more informed decisions on which ceramic brackets they will use to optimize practice efficiency and minimize the amount of risk to the patient.

METHODS

The study was approved by the Institutional Review Board of Louisiana State University Health Sciences Center of New Orleans (IBC #19024). Four different manufacturers' ceramic brackets were selected to test their tie wing fracture resistance. Ten maxillary right 0.022-inch slot central incisor brackets from each of the 4 manufacturers underwent fracture testing of their distogingival tie wings. The sample brackets included polycrystalline Ormco Symetri (Ormco, Orange, Calif, USA), 3M Clarity (3M, Monrovia, Calif, USA), Dentsply Ovation S (Dentsply, York, Pa, USA), and monocrystalline American Radiance Plus (AO, Sheboygan, Wis, USA). 3M Clarity brackets were chosen as a comparison bracket because they have been available for many years and have been the subject of much bracket research. The remaining 3 brackets were chosen as they are newer to the market and lack published data concerning their properties and performance behavior.

The sample brackets were bonded to stainless steel washers utilizing a 2-part epoxy system, JB Weld (JB Weld, Sulphur Springs, Tex, USA). It achieves an initial set after 4-6 hours and a full cure is reached within 15-24 hours. When fully cured, it has a tensile strength of 5020 PSI. The epoxy was mixed according to the manufacturer's recommendations, and a thin layer was placed on each washer. The ceramic brackets were placed on the epoxy using cotton pliers and allowed to achieve a full cure of 24 hours. Each bracket was mounted with the distal gingival tie wing facing the outer surface of the washer and as close to the edge of the washer as possible (Figure 1). Care was taken to ensure that

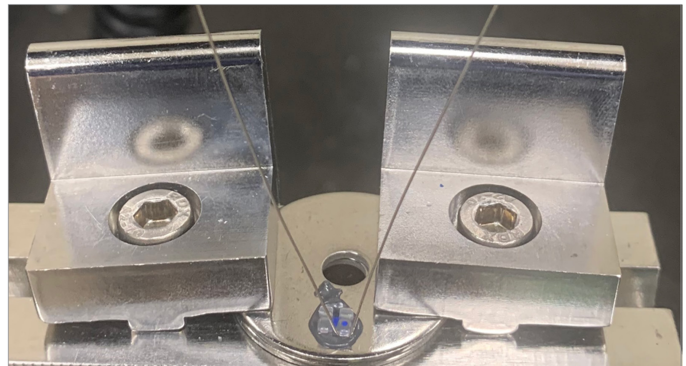

Figure 1. Bracket mounting with the steel ligature engaged under the tie wing

no epoxy flowed over the base of the ceramic brackets or under the tie wings as to avoid compromising the ability to place a steel ligature under the tie wings or further reinforce its strength.

The methodology of this research was based on a previous study by Johnson and a previous study by Sanchez with some modifications.[2,18] This study utilized the sample size calculation of the Johnson study which found the need of 10 samples per group.[2] Using a universal testing machine (Instron 5566, Norwood, Mass, USA), the study tested ceramic bracket tie wing tensile strength, defined as the maximum load that a material can support without fracture when being stretched, divided by the original cross-sectional area of the material.[2] The mechanical testing of the tie wings utilized a 0.012-inch stainless steel ligature wire looped under the distal gingival tie wing of each sample. The looped ligature wire was secured firmly around a grooved rod which was placed through the Instron machine load cell (10 kN) to ensure that the ligature did not fail or slip (Figure 2). A new identical wire was used for each group. The stainless steel washers were securely clamped into place. A vertical tensile force was applied via the ligature wire at a crosshead speed of 5 mm/min until fracture. The tensile force/load at failure was recorded with Instron's Bluehill 3® software (Instron). The samples were not subjected to any methodology that mimicked the intraoral environment prior to testing because Alexopoulou et al.[19] found no change in the mechanical properties of monocrystalline or polycrystalline brackets following intraoral aging.

Fracture strength, reported in megapascals (MPa), was calculated by dividing the maximal tensile force in Newtons (N) by the original cross-sectional area of the tie wing (mm^2).

Statistical Analysis

The objective of the analyses was to compare the tie wing fracture resistance of ceramic brackets of different brands (10 samples per group). The homogeneity of variance assumption was tested first. If the assumption was violated, the Welch ANOVA tests were used to test the overall difference. Post hoc tests were used to provide pairwise comparisons and pairwise *P*-values were adjusted for the multiple comparison using the Tukey method. In addition, non-parametric tests (Kruskal–Wallis test with Dwass-Steel-Critchlow-Fligner method (DSCF) procedure for pairwise comparisons) were used to confirm the results for small sample sizes. All analyses were performed using Statistical Analysis System (SAS) (version 9.4, Cary, NC, USA).

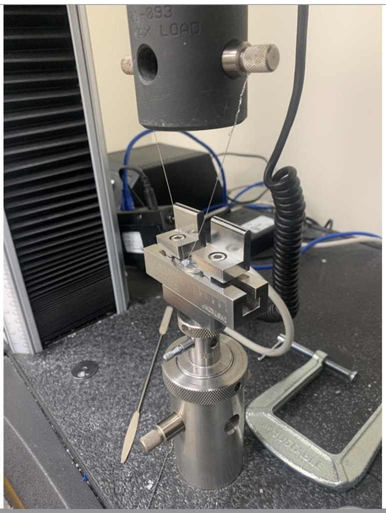

Figure 2. Tensile strength setup of the specimen

RESULTS

The descriptive analysis of tensile strength at peak local maximum for each group is shown in Table 1. The Welch analysis of variance (ANOVA) test results indicated that there was a significant overall difference between the 4 groups in regard to their mean tensile strength at peak local maximum (MPa) with a *P*-value of less than .0001 (Table 2). The brackets from 3M showed a significantly larger mean tensile strength than the brackets by American, Dentsply, and Ormco. The 3M brackets are followed by American and Ormco, which have a significantly higher resistance to fracture than the Dentsply brackets.

Since the sample size is relatively small for each manufacturer, we further applied Kruskal–Wallis to confirm if there are significant differences in the resistance of the tie wings to fracture among the manufacturers. The *P*-value from the test was <.0001, therefore the conclusion is the same as that from the ANOVA. Then the pairwise multiple comparison analysis was performed to find the difference among each pair of the manufacturers using the DSCF procedure (20). Using the DSCF method, Table 3 shows that each pair of the manufacturers are significantly different in resistance with the *P*-value ranging from .0009 to .0037.

When the groups were compared to each other using a post hoc analysis with adjusted *P*-values of less than .0001 (using the Tukey method), they showed a significant difference in mean tensile strength at peak local maximum (MPa) with the exception being the American Radiance and Ormco Symetri brackets (Table 4).

DISCUSSION

Many different types of ceramic brackets are available on the market today from which an orthodontist can choose. As mentioned, there is an increased demand for esthetics in orthodontics at the present time.[1] When offering ceramic appliances as a

Table 1. Fracture resistance of the tested brackets

Group	No. Obs	Mean (MPa)	Std Dev (MPa)	Lower 95%, CL for Mean	Upper 95%, CL for Mean
3M Clarity	10	134.25	9.92	127.16	141.34
American Radiance	10	61.91	2.99	59.76	64.05
Ormco Symetri	10	57.69	7.25	52.50	62.88
Dentsply Ovation	10	30.63	1.69	29.43	31.84

CL, Confidence Level

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Table 2. ANOVA analysis results

Source	DF	Sum of Squares	Mean Square	F	Pr > F
Model	3	58897.99805	19632.66602	482.55	<0.0001
Error	36	1464.65905	40.68497		
Corrected total	39	60362.65710			

DF, Degree of Freedom.

treatment modality, it is important to have a bracket that maintains its integrity and does not fracture. In doing so, the orthodontist saves cost, time, and the inconvenience of replacement to both the clinician and the patient. Bracket fracture also affects the ability of the bracket to effectively transfer orthodontic forces to the tooth which may affect overall treatment time. Tie wing fractures, bracket fractures, and debonded brackets all require replacement.[11,18] The primary aim of the present study was to determine if there were differences in the fracture resistance of the tie wings from 4 manufacturers' popular ceramic brackets.

This study was able to confirm that there are significant differences in the resistance of the tie wings to fracture among the manufacturers tested. This is similar to the results from the Johnson study which also confirmed that bracket tie wing fracture will vary from manufacturer to manufacturer.[2] As shown by the data in Table 1, the 3M Clarity brackets had the highest resistance to tie wing fracture followed by American Radiance Plus, Ormco Symetri, and lastly, Dentsply Ovation S. The data in Table 2 showed that American Radiance Plus and Ormco Symetri did not have a significant difference in their tie wing fracture resistance.

When evaluating tested polycrystalline versus monocrystalline brackets, we are not able to confirm that one manufacturing method has a higher resistance to fracture than another. Comparing the mean tensile strengths at peak maximum of all the polycrystalline brackets (3M Clarity, Ormco Symetri, and Dentsply Ovation S), one sees a large range in the reported averages with the monocrystalline bracket (American Radiance Plus) falling in the middle. When comparing and contrasting with the Johnson study, the researchers found that their single monocrystalline bracket could not be fractured prior to the steel ligature breaking which occurred at a mean MPa of 198.65, while the polycrystalline brackets were able to fracture.[2] In the current study, there was no steel ligature breakage prior to fracture of the tie wing despite using a smaller (0.012-inch vs. 0.014-inch) steel ligature. A smaller ligature was chosen to provide more engagement of the tie-wing due to the depth of the tie-wing undercut. As previously mentioned, it is suggested that the differences in manufacturing processes result in disparities in strength with monocrystalline being stronger than polycrystalline.[2,13,14] If we assess our data with the elimination of the polycrystalline "outlier" (3M Clarity), then we do see that the monocrystalline (American Radiance Plus) was stronger than the remaining polycrystalline brackets. However, as mentioned, the American Radiance Plus and the Ormco Symetri did not have statistically significant differences. A further study could be performed with more groups of each type of manufacturing process to determine if one process is stronger than the other.

Table 3. Dwass, steel, Critchlow-Fligner method for pairwise 2-sided multiple comparison analysis

Group	Wilcoxon Z	DSCF Value	Pr > DSCF
Dentsply Ovation vs. American Radiance	−3.7811	5.3472	0.0009
Dentsply Ovation vs. Ormco Symetri	−3.7811	5.3472	0.0009
Dentsply Ovation vs. 3M Clarity	−3.7811	5.3472	0.0009
American Radiance vs. Ormco Symetri	3.7796	5.3452	0.0009
American Radiance vs. 3M Clarity	3.4017	4.8107	0.0037
Ormco Symetri vs. 3M Clarity	−3.4773	4.9176	0.0028

Another factor that has been reported to facilitate fracture of ceramic brackets is scratches on the surface of the ceramic that seem to impact the tensile strength characteristics of the ceramic.[21,22] Even small scratches have been reported to reduce the force needed for fracture. To avoid this impact on the current study, extreme care was taken to avoid scratching the surface of the brackets when mounting samples or engaging ligature wire. If scratches to the ceramic surface leads to fracture, orthodontists need to take care in their practice to avoid scratching the ceramic surface when tying in archwires. Consideration should be given to using elastic ligatures or coated ligatures for archwire ligation which may reduce the frequency of ceramic bracket fracture.

Care was taken to maintain the most standardization possible throughout the entire process which included the orientation and mounting of the brackets in the same manner (to the stainless steel washers and in the Instron machine), usage of new ligature wires for each group, and calibration of the Instron

Table 4. Post hoc Tukey's test

Adjusted *P*	3M Clarity	American Radiance	Dentsply Ovation	Ormco Symetri
3M Clarity	_______	<0.0001	<0.0001	<0.0001
American Radiance	_______	_______	<0.0001	0.3562
Dentsply Ovation	_______	_______	_______	<0.0001
Ormco Symetri	_______	_______	_______	_______

equipment. However, operator error could be a limitation to this study. Variations during the manufacturing process of the brackets may be a limitation, as well. Further research with more groups and larger sample sizes could further validate the information. An alternative study that mimics clinical tie wing fracture, similar to intraoral forces while eating, could be beneficial.

In summary, it does appear to be wise to choose a bracket with the highest resistance to tie wing fracture to combat the issue of ceramic brackets breaking and needing to be replaced throughout orthodontic treatment.

CONCLUSION

3M Clarity brackets had the highest resistance to tie wing fracture. Dentsply Ovation S had the lowest resistance to tie wing fracture. Ormco Symetri and American Radiance did not have statistically different resistances to tie-wing fracture.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Louisiana State University Health Sciences Center, (Approval No: 19024).

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

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