ABSTRACT

Objective: To ascertain the dimensional accuracies of some commonly used ceramic self-ligation brackets and the amount of torsional play in various bracket–archwire combinations.

Materials and Methods: Four types of 0.022-inch slot ceramic self-ligating brackets (upper right central incisor), three types of 0.018-inch ceramic self-ligating brackets (upper right central incisor), and three types of rectangular archwires (0.016 × 0.022-inch beta-titanium [TMA] (Ormco, Orange, Calif), 0.016 × 0.022-inch stainless steel [SS] (Ortho Technology, Tampa, Fla), and 0.019 × 0.025-inch SS (Ortho Technology)) were measured using a stereomicroscope to determine slot widths and wire cross-sectional dimensions. The mean acquired dimensions of the brackets and wires were applied to an equation devised by Meling to estimate torsional play angle (γ).

Results: In all bracket systems, the slot tops were significantly wider than the slot bases (P < .001), yielding a divergent slot profile. Clarity-SLs (3M Unitek, Monrovia, Calif) showed the greatest divergence among the 0.022-inch brackets, and Clippy-Cs (Tomy, Futaba, Fukushima, Japan) among the 0.018-inch brackets. The Damon Clear (Ormco) bracket had the smallest dimensional error (0.542%), whereas the 0.022-inch Empower Clear (American Orthodontics, Sheboygan, Wis) bracket had the largest (3.585%).

Conclusions: The largest amount of theoretical play is observed using the Empower Clear (American Orthodontics) 0.022-inch bracket combined with the 0.016 × 0.022-inch TMA wire (Ormco), whereas the least amount occurs using the 0.018 Clippy-C (Tomy) combined with 0.016 × 0.022-inch SS wire (Ortho Technology). (Angle Orthod. 2016;86:804–809.)

KEY WORDS: Torsional play; Ceramic self-ligating brackets; Slot dimensions

INTRODUCTION

Andrews’s straight-wire appliance system allows clinicians to move teeth in three dimensions using straight wires.1–3 The system involves inserting rectangular wires into bracket slots that have been specifically designed according to a prescription. Teeth can be properly aligned, angulated, and inclined by means of an intimate fit between the wire and the bracket slot.4 Clinicians expect that the interaction between these two elements will provide clinical efficiency, assuming that manufacturers reliably report the dimensions of the appliance and wires. However, previous studies have reported dimensional inaccuracies in the brackets and archwires, often creating excessive torsional play.4,6 As a result, torque is insufficiently controlled, especially in the incisors in extraction cases, and this compromises clinical outcome.

Self-ligation brackets have become widely used because they demand shorter chair time, cause minimal friction, and can be easily manipulated by clinicians.5–9 Moreover, many patients find metal brackets unattractive, preferring esthetic appliances,10 and ceramic self-ligation brackets can be used to this end without compromising the low-frictional characteristics.9

Despite this, few studies have been carried out addressing the dimensional accuracies of ceramic self-ligation brackets. The purpose of this study was to ascertain the dimensional accuracies of some commonly used ceramic self-ligation brackets as well as...
the amount of torsional play in various bracket–archwire combinations. The specific aims were to (1) quantify the manufacturer error in the bracket slots and archwires, (2) measure the edge rounding of the wires, and (3) calculate the amount of torsional play using the mean values of the study samples.

MATERIALS AND METHODS

Four types of 0.022-inch (0.559 mm) ceramic self-ligating brackets (upper right central incisor) and three types of 0.018-inch (0.457 mm) ceramic self-ligating brackets (upper right central incisor) were investigated (Table 1; n = 20 for each type). The following three types of rectangular wires were selected for dimensional analysis of cross-sections: 0.016 × 0.022-inch beta-titanium (TMA), (Ormco, Orange, Calif), 0.016 × 0.022-inch stainless steel (SS) (Ortho Technology, Tampa, Fla), and 0.016 × 0.022-inch stainless steel (SS) (Ortho Technology), (Table 1; n = 10 for each type). This analysis included measurements of height, width, and corner radai of the wire edge.

A stereomicroscope (SMU-Z, Nikon, Tokyo, Japan) was used to measure the dimensions of the brackets and wire cross-sections. To this end, brackets were fixed to a glass slide using wax, and the wax allowed the brackets to be maneuvered in the stereomicroscope so that the bracket slots could be photographed at a perpendicular angle. Proper orientation of the bracket slots was confirmed by reviewing the images. The reliability of the dimensions measured with the stereomicroscope was assessed by conducting a preliminary study of randomly selected brackets (n = 20) to compare the slot dimensions acquired from the scanning electron microscope (HITACHI S-4700, Hitachi, Tokyo, Japan) and the stereomicroscope. The results indicated no significant difference in the slot widths of the brackets measured with both microscopes (P > .05), validating the method of measurement used in this study.

The images of the brackets’ mesial profiles were exported to the NIS-Elements software (Nikon), and the slot-base width and top width were measured in millimeters, whereas the slot divergence angle was measured in degrees (Figure 1). The width and height of the wire cross-sections were also measured. Furthermore, because the wires had two pairs of identical corner bevels, the radii of the two different corners of the wire cross-sections were measured (Figure 2). The differences were calculated between the nominal dimensions on the one hand and the measured slot-base width and top width on the other. The dimensional error is shown in Tables 2 and 3 as a percentage error of the nominal width. Because of the various slot designs of the self-ligation bracket systems, which are associated with a type of wire-slot interaction known as either “passive” or “active,” slot-height dimensions are inconsistent with the nominal dimensions, therefore they were excluded for evaluation.

Torsional play (γ) was calculated in degrees by applying the mean acquired dimensions of the brackets and archwires to an equation devised by Meling et al.,11

\[ \gamma = \arcsin\left(\frac{H - 2r}{d}\right) - \arcsin\left(\frac{h - 2r}{d}\right) \]

where “H” is the height of bracket slot, “h” the height of wire, “d” the distance between the centers of the two circles that fit the corners of the wire, and “r” the radius of the wire rounding.

Statistics

Data were analyzed using SPSS 15.0 software (IBM, Armonk, N.Y.). The means and 95% confidence intervals of the bracket–slot dimensions and archwire cross-sections were calculated in addition to the percentage error from the given size. The base and top widths were compared using a t-test, and the dimensions were compared among the brackets and archwires using analysis of variance and Tukey’s test. P values < .05 were considered statistically significant.

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Table 1. Self-Ligating Brackets and Orthodontic Archwires Used in This Study

<table>
<thead>
<tr>
<th>Bracket Manufacturer</th>
<th>Slot Size (Inch)</th>
<th>Clip Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empower Clear</td>
<td>0.018, 0.022</td>
<td>Active</td>
</tr>
<tr>
<td>Damon Clear</td>
<td>0.022</td>
<td>Passive</td>
</tr>
<tr>
<td>Clippy-C</td>
<td>0.018, 0.022</td>
<td>Active</td>
</tr>
<tr>
<td>Clarity-SL</td>
<td>0.018, 0.022</td>
<td>Passive</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Archwire Manufacturer</th>
<th>Dimension (Inch)</th>
<th>Lot No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Friction TMA</td>
<td>0.016 × 0.022</td>
<td>211–1412</td>
</tr>
<tr>
<td>TruForce SS</td>
<td>0.016 × 0.022</td>
<td>8000–207</td>
</tr>
<tr>
<td>TruForce SS</td>
<td>0.019 × 0.025</td>
<td>8000–113</td>
</tr>
</tbody>
</table>

* Empower Clear, American Orthodontics, Sheboygan, Wis; Damon Clear, Ormco, Orange, Calif; Clippy-C, Tomy, Futaba, Fukushima, Japan; Clarity-SL, 3M Unitek, Monrovia, Calif. SS indicates stainless steel; TMA, beta titanium.
RESULTS

The slot dimensions of different self-ligation bracket systems significantly differed from each other; this was true for both the 0.018-inch ($P < .001$) and 0.022-inch ($P < .001$) systems (Tables 2 and 3). Slot bases ranged from 0.453 mm to 0.464 mm in the 0.018-inch brackets (Table 2), and from 0.550 mm to 0.570 mm in width in the 0.022-inch brackets (Table 3). The smallest dimensional error was in the Damon Clear brackets (0.542%; Ormco), and the largest was in the 0.022-inch Empower Clear bracket (3.585%; American Orthodontics, Sheboygan, Wis).

In contrast, slot tops were wider than the given value in all types of brackets, with the greatest error in the 0.018-inch Clarity-SL brackets (3M Unitek, Monrovia, Calif), which had a slot top 30.9% wider than reported. These were followed by the 0.018-inch Clippy-C (Tomy, Futaba, Fukushima, Japan), which were 22.5% wider than reported at the slot top. In all brackets, slot tops were significantly wider than slot bases ($P < .001$). All brackets had a divergent slot profile, with the 0.022-inch Clarity-SL (3M Unitek, Monrovia, Calif) and 0.018-inch Clippy-C (Tomy) brackets showing the largest slot divergence angle, with statistical significance ($P < .05$). Table 4 shows the sizes of the archwire cross-sections. All wires had manufacturing errors of less than 2%. The 0.016 $\times$ 0.022-inch SS (Ortho Technology) wire and the 0.019 $\times$ 0.025-inch SS (Ortho Technology) wire were oversized, whereas the 0.016 $\times$ 0.022-inch TMA wire (Ormco) height was undersized. The 0.016 $\times$ 0.022-inch TMA wire (Ormco)

Figure 1. Stereomicroscopic images of the brackets' mesial profiles that were used to measure the slot dimensions: slot-base width (a), top width (b), and slot divergence angle (c). (A: Empower Clear [American Orthodontics, Sheboygan, Wis], B: Damon Clear [Ormco, Orange, Calif], C: Clippy-C [Tomy, Futaba, Fukushima, Japan], D: Clarity-SL [3M Unitek, Monrovia, Calif]).

Figure 2. Width, height, and 2 corner radii of edge bevels in the wire cross-section.
was significantly shorter in height than the 0.016 \times 0.022-inch SS (Ortho Technology) wire ($P < .001$), whereas the widths were not significantly different ($P = .342$). Regarding the amount of corner beveling, the radius of corner 1 in the 0.016 \times 0.022-inch TMA wire (Ormco) was significantly smaller ($P < .05$) than in the other two types of wire. Conversely, the radius of corner 2 did not differ among the three types of wires.

Table 5 shows the theoretical torsional play with different combinations of brackets and archwires. Because the 0.016 \times 0.022-inch TMA wire (Ormco) was shorter in height than the 0.016 \times 0.022-inch SS wire (Ortho Technology), the torsional play of the 0.016 \times 0.022-inch TMA wire (Ormco), in all types of brackets, was greater by 11.39 degrees to 14.49 degrees in the 0.022-inch brackets and by 7.49 degrees to 7.70 degrees in 0.018-inch brackets. Empower Clear brackets (American Orthodontics), in both the 0.018-inch and 0.022-inch systems, had the greatest torsional play (Table 5).

**DISCUSSION**

Although most manufacturers do not state their engineering tolerances for bracket slot variations, manufacturing inaccuracies do exist as a result of errors in manufacturing processes and material parameters.\(^5,12\) As the slot–archwire difference is a major contributor to torsional play, the authors aimed to measure the actual slot sizes and wire dimensions and thus accurately quantify the theoretical torsional play in ceramic self-ligation brackets.

All study samples of self-ligating ceramic brackets had diverging slots, with the slot tops being 10% to 30% wider than the given value. However, the slot bases were close to the nominal widths, with a dimensional error of 1% to 2%. Regarding slot dimensions, Bhalla et al.\(^6\) reported that 0.022-inch In-Ovation-C (Dentsply, York, Penn), Clarity-SL (3M Unitek) brackets had slot tops that were wider than the given value by 11.4% and 9.5%, respectively, and that the bracket slots diverged. According to Major et al.,\(^5\) In-Ovation metal brackets (Dentsply), and Damon metal brackets (Ormco) were oversized, and In-Ovation bracket (Dentsply), slots were divergent, whereas Damon bracket slots (Ormco) were nearly parallel. Moreover, Cash et al.\(^4\) in their study of conventional and self-ligating brackets, reported that all brackets were larger than stated by the manufacturer, with an error range of 5% to 24%. Regarding the slot size differences among different self-ligation systems, Bhalla et al.\(^6\) stated that there was considerable slot-size variation among different 0.022-inch bracket systems, coinciding with our results.

Table 2. Slot Dimensions of 0.018-Inch Self-Ligating Brackets\(^*\)

<table>
<thead>
<tr>
<th>Bracket(^a)</th>
<th>Base Width*** (mm)</th>
<th>Top Width*** (mm)</th>
<th>Divergence Angle*** (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>95% CI</td>
<td>Dimensional Error, %</td>
</tr>
<tr>
<td>Clarity-SL</td>
<td>0.460(^1)</td>
<td>0.458–0.463</td>
<td>1.5</td>
</tr>
<tr>
<td>Clippy-C</td>
<td>0.453(^2)</td>
<td>0.452–0.455</td>
<td>–1.8</td>
</tr>
<tr>
<td>Empower Clear</td>
<td>0.464(^3)</td>
<td>0.462–0.465</td>
<td>3.2</td>
</tr>
</tbody>
</table>

\(^a\) The same superscript numbers within the same column are not significantly different ($P > .05$).

\(^1\) Clarity-SL, 3M Unitek, Monrovia, Calif; Clippy-C, Tomy, Futaba, Fukushima, Japan; Empower Clear, American Orthodontics, Sheboygan, Wis.

\(^2\) CI indicates confidence interval.

\(^*\) $P < .001$ for analysis of variance of slot dimensions among different self-ligation systems.

Table 3. Slot Dimensions of 0.022-Inch Self-Ligating Brackets\(^*\)

<table>
<thead>
<tr>
<th>Bracket(^a)</th>
<th>Base Width*** (mm)</th>
<th>Top Width*** (mm)</th>
<th>Divergence Angle*** (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>95% CI</td>
<td>Dimensional Error, %</td>
</tr>
<tr>
<td>Clarity-SL</td>
<td>0.550(^1)</td>
<td>0.549–0.552</td>
<td>–2.7</td>
</tr>
<tr>
<td>Clippy-C</td>
<td>0.556(^2)</td>
<td>0.553–0.558</td>
<td>–1.0</td>
</tr>
<tr>
<td>Damon Clear</td>
<td>0.560(^3)</td>
<td>0.559–0.562</td>
<td>0.5</td>
</tr>
<tr>
<td>Empower Clear</td>
<td>0.570(^4)</td>
<td>0.568–0.572</td>
<td>3.6</td>
</tr>
</tbody>
</table>

\(^a\) The same superscript numbers within the same column are not significantly different ($P > .05$).

\(^1\) Clarity-SL, 3M Unitek, Monrovia, Calif; Clippy-C, Tomy, Futaba, Fukushima, Japan; Damon Clear, Ormco, Orange, Calif; Empower Clear, American Orthodontics, Sheboygan, Wis.

\(^2\) CI indicates confidence interval.

\(^*\) $P < .001$ for analysis of variance of slot dimensions among different self-ligation systems.
The archwires in our study had dimensional variations within 2% of the given value, which is significantly less than the errors in the ceramic self-ligation bracket slots assessed. All width and height measurements of the wire cross-sections but the height of the 0.016 × 0.022-inch TMA (Ormco), was greater than stated by the manufacturer. Our results corroborate those of Meling et al., who reported that most wires are larger than stated. In contrast, Fischer-Brandies reported that archwires had cross-sections that were significantly smaller than stated. Although these wire-dimension variations are relatively small, their effect on the amount of torsional play may be clinically significant when combined with bracket size discrepancies.

Variations in wire-edge beveling also contribute to increased torsional play. In our study, corner radii, both within the same wire and among different wires, varied depending on the wire size and manufacturer. Sernetz suggested that a radius of at least 0.04 mm is needed at the edge bevel to ensure patient comfort, and standardization of the wire bevel is needed. Moreover, Meling et al. reported considerable variations in the amount of edge bevel, corroborating our results.

Torsional play calculations, using the mean values from our study samples, revealed that dimensional differences in the same-sized SS (Ortho Technology) and TMA (Ormco) wires resulted in an approximate 10-degree difference in torsional play; this was true in both the 0.018-inch and 0.022-inch brackets. Because the play angle calculated does not take into account the different physical properties of the wires, this difference must be the result of discrepancies in the actual dimensions between the two wires. In fact, the 0.016 × 0.022-inch TMA wire (Ormco) cross-section was significantly shorter in height than the 0.016 × 0.022-inch SS wire (Ortho Technology) ($P < .01$). The accuracy of Meling’s equation for calculating theoretical torsional play has been confirmed in previous studies. For instance, Odegaard et al. compared measured torque with that derived from Meling et al., and they found 0.6 degrees of difference between measured and calculated torsional play in a 0.016 × 0.022-inch wire inside a 0.018-inch standard edgewise bracket. Similar results were reported by Fischer-Brandies et al. who also compared measured torsional play with that derived using Meling’s formula. Because Meling’s formula incorporates the amount of wire bevel, more accurate torsional play values can be yielded.

However, one needs to understand that Meling’s formula assumes the slot walls are parallel. In reality, most bracket slots diverge, and when slot-base widths are used for calculations, the actual torsional play may be greater than estimated depending on the degree of divergence. In our study, we used slot-base widths because different types of bracket slot base have similar designs, regardless of the self-ligating mechanism; this makes measurements more reliable.

The limitation of our study was that torsional play was not directly measured, and thus the possible effects of active-type self-ligation brackets on torsional play could not be observed. Manufacturers claim that when the archwire fills the slot and comes into contact with the ligating clip, the wire is pushed against the slot and torsional play is decreased. Furthermore, theoretical torque is an estimate when there is no loading. As torsional play increases with loading,
the effects of loading on the amount of torsional play may provide valuable information. This warrants further research.

CONCLUSIONS

- All bracket slots studied have a divergent slot profile, with the greatest divergence being in the Clarity-SL (3M Unitek) bracket for the 0.022-inch system ($P < .001$), and in the Clippy-C (Tomy) bracket for the 0.018-inch system ($P < .001$).
- In both the 0.018-inch and 0.022-inch brackets, the base of the bracket slot has minimal dimensional errors, ranging from $-1.520\%$ to $2.004\%$ in the 0.022-inch system, and $-0.835\%$ to $1.482\%$ in the 0.018-inch system. However, the tops of the slots are significantly wider than stated in all types of brackets, with the greatest discrepancy being in the Clarity-SL brackets (3M Unitek) both in the 0.018-inch ($30.887\%$) and 0.022-inch ($20.373\%$) systems.
- The given cross-sectional dimensions of the arch-wires are relatively accurate, with dimensional variations within $2\%$, whereas the amount of edge bevel varied widely.
- The largest amount of theoretical play is observed using the Empower Clear 0.022-inch bracket (American Orthodontics) combined with the $0.016 \times 0.022$-inch TMA wire (Ormco) whereas the least amount occurs using the 0.018-inch Clippy-C bracket (Tomy) combined with the $0.016 \times 0.022$-inch SS wire (Ortho Technology).

REFERENCES