Influence of Stainless Steel Inserts on the Resistance to Sliding of Esthetic Brackets with Second-Order Angulation in the Dry and Wet States

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Abstract: Stainless steel (SS) inserts have been added to plastic, ceramic, and composite brackets to improve their frictional characteristics while preserving their esthetic appeal. When coupled with SS archwires, the resistances to sliding of esthetic brackets with and without SS inserts were compared with control brackets of SS. The resistances to sliding were measured in both the dry and wet (saliva) states at 32 second-order angles between $-12^\circ$ and $+12^\circ$. When clearances existed between the walls of the brackets and the archwires, the resistances to sliding for the esthetic brackets without inserts were between 38 cN in the dry state and 73 cN in the wet state; those of the esthetic brackets with inserts ranged from 42 cN in the dry state to 65 cN in both states. The resistances to sliding of the SS brackets equaled 38 and 52 cN in the dry and wet states, respectively. When clearances no longer existed, the resistances to sliding for the esthetic brackets with and without inserts generally increased with angulation at a rate equal to or greater than that of the SS brackets—except for the polycarbonate (PC) brackets in the dry state. Because PC brackets without inserts elastically deformed, they had lower resistances to sliding when deformation occurred. For the polycrystalline alumina brackets without inserts, the resistances to sliding increased rapidly and nonlinearly as angulation increased above $4.8^\circ$. Upon examination, the presence of scratches on the archwires and SS debris on the brackets was observed. The addition of these particular SS inserts did not considerably improve the resistance to sliding over those esthetic brackets without inserts. (Angle Orthod 2003;73:167–175.)

Key Words: Brackets; Friction; Stainless steel; Esthetics; Angulation; Inserts

INTRODUCTION

Among the materials used to make orthodontic brackets, stainless steel (SS) is the most widely employed. The low cost and low reactivity of SS are two reasons for its popularity. When clearances exist (the passive configuration), the frictional properties of SS archwire-bracket couples are the “gold standard” for orthodontic appliances. Once clearances do not exist (the active configuration), the resistance to sliding (RS) of the SS brackets are profoundly affected by the choice of archwire material.

In the early 1970s, polycarbonate (PC) brackets were developed as an esthetic replacement for SS. The soft surfaces, staining, and poor dimensional stability of PC brackets made them unsuitable for clinical use. Additionally, their frictional behavior reportedly was poor when compared with SS brackets. By the late 1980s, the polycrystalline alumina (PCA) brackets provided orthodontists with an esthetic alternative with few of the problems of PC brackets, although the friction encountered when sliding with PCA brackets was higher than SS brackets. Most recently, esthetic brackets composed of ceramic-reinforced polycarbonate (CRP) were manufactured, in which ceramic particles provided strength to the PC matrix, which in turn promised a better sliding surface than PCA. Bazakidou et al reported that CRP brackets exhibited lower friction when compared with PCA and SS brackets.

Some orthodontists avoid using esthetic brackets because they perceive that these brackets exhibit poor frictional behavior. The additions of SS inserts to the slots of esthetic brackets were expected to improve their frictional and mechanical properties while retaining their esthetic appeal. More specifically, esthetic brackets with SS inserts may have similar frictional properties to the “gold standard” SS
TABLE 1. Bracket, Archwire, and Ligature Materials Evaluated

<table>
<thead>
<tr>
<th>Material</th>
<th>Design</th>
<th>Product</th>
<th>Nominal dimensions mm (inch)</th>
<th>Angulation (°)</th>
<th>Torque (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brackets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>Conventional (-C)</td>
<td>Miura®</td>
<td>0.559 (0.022)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>Insert (-I)</td>
<td>Plastic®</td>
<td>0.559 (0.022)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Polycrystalline alumina (PCA)</td>
<td>Conventional (-C)</td>
<td>Allure®</td>
<td>0.559 (0.022)</td>
<td>0</td>
<td>-7</td>
</tr>
<tr>
<td>Polycrystalline alumina (PCA)</td>
<td>Insert (-I)</td>
<td>Clarity®</td>
<td>0.559 (0.022)</td>
<td>0</td>
<td>-7</td>
</tr>
<tr>
<td>Ceramic-reinforced polycarbonate (CRP)</td>
<td>Conventional (-C)</td>
<td>Vogue®</td>
<td>0.559 (0.022)</td>
<td>0</td>
<td>-7</td>
</tr>
<tr>
<td>Ceramic-reinforced polycarbonate (CRP)</td>
<td>Insert (-I)</td>
<td>Spirit MB®</td>
<td>0.559 (0.022)</td>
<td>0</td>
<td>-7</td>
</tr>
<tr>
<td>Stainless steel (SS)</td>
<td></td>
<td>Mini Diamond Twin®</td>
<td>0.559 (0.022)</td>
<td>0</td>
<td>-7</td>
</tr>
<tr>
<td>Archwire</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stainless steel (SS)</td>
<td></td>
<td>Rectangular®</td>
<td>0.457 × 0.635 (0.018 × 0.025)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ligature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stainless steel (SS)</td>
<td></td>
<td>Preformed®</td>
<td>0.254 (0.010)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Rocky Mountain Orthodontics, Denver, Colo, USA.
* Dentaurum, Pfzorheim, Germany.
* GAC International, Inc., Islandia, NY, USA.
* 3M/Unitex, Monrovia, Calif, USA.
* Sybron Dental Specialties Ormco, Orange, Calif, USA.
* SLOT, for which 1 mm = 0.03937 inch.14
* SIZE, for which 1 mm = 0.03937 inch.14
* Diameter, for which 1 mm = 0.03937 inch.

brackets because the material in contact with the archwire was the same for both types of brackets. Presently, for second-order angulations in the dry and wet (saliva) states, the resistances to sliding of PC, PCA, and CRP brackets with SS inserts, which were coupled with SS archwires, were compared with other conventional PC, PCA, and CRP brackets without SS inserts and to the control SS brackets. In the passive configuration, the brackets with SS inserts generally exhibited comparable or less friction than the esthetic brackets without inserts. In the active configuration, the binding behavior of the brackets was mostly comparable with or greater than the SS brackets.

MATERIALS AND METHODS

Materials and dimensions

Conventional esthetic brackets (PC-C, PCA-C, and CRP-C) were compared with esthetic brackets with SS inserts (PC-I, PCA-I, and CRP-I) that had the same bulk material and similar nominal dimensions (Table 1). Conventional SS brackets were used as a control (Figure 1a). For each PCA or SS bracket design, two brackets were evaluated at 32 second-order angles (θ) in the dry and wet (saliva) states for a total of 384 tests (3 designs × 2 brackets × 32 θ × 2 states). The SLOT and WIDTH dimensions of these brackets were measured (Appendix). Because the conventional PC and CRP brackets could deform at high θ values, two brackets of each PC or CRP bracket design were tested at each θ value in the dry and wet states, which, for all 32 θ values, resulted in a total of 512 tests (4 designs × 2 brackets per angle × 32 θ × 2 states). For 20 brackets of the 128 brackets that were tested for each of these designs, the dimensions were measured (Appendix). The brackets were coupled with 0.457 × 0.635 mm SS archwires (Table 1) for which the SIZE dimensions were also measured (Appendix).

Morphologies of the brackets

A scanning electron microscope (SEM; JEOL JSM-6300, JEOL America, Peabody, Mass) was used to evaluate the morphologies of the different brackets. Each bracket was mounted on an aluminum stud using carbon adhesive tape. Using a vapor-deposition process, all esthetic brackets with and without SS inserts were coated with gold-palladium to improve their conductivity. Each bracket was examined at 15 keV in the secondary electron mode.

Frictional testing and regression analyses

A custom frictional testing apparatus was mounted on the crosshead of an Instron mechanical testing machine (Model TTCM, Canton, Mass) and used to measure the drawing force (which equals twice the RS) required to slide a bracket a distance of two mm along the archwire at a rate of one cm/min.15,17 The brackets and archwires were mounted as described elsewhere (Appendix). Each 0.254 mm SS ligature wire (Table 1) applied a ligation force of 300 cN to its archwire by a load cell that was controlled by a servomotor feedback loop.18,19 Two sets of poly(tetrafluoroethylene) bearings simulated adjacent brackets at a distance of 18 mm from the bracket being evaluated.15,20 This dis-
INFLUENCE OF INSERTS ON RESISTANCE TO SLIDING

FIGURE 1. For control SS brackets: (a) its scanning electron micrograph; (b) plots of the RS as a function of angulation (θ) in both the dry (D) and wet (saliva [S]) states including the linear regression lines for the passive configurations (left side of plot) and the active configurations (right side of plot); (c) in the passive configuration for both the dry and wet states, linear regression lines for θ vs FR, which equaled RS; and (d) in the active configuration for both the dry and wet states, linear regression lines of relative angulation (θ_r, which equaled θ minus the critical contact angle for binding [θ_c]) vs elastic binding (BI), which equaled RS minus FR.

Additional experiments

To ascertain whether the PC-C and CRP-C brackets were elastically deforming, four brackets of each were mounted (Appendix). The spaces between the tie-wings of the brackets and the walls of the mounts were filled with cement to inhibit the tie-wings from flexing under the force applied by the archwire to the slot edges. Two brackets each of the supported PC-C and CRP-C brackets were tested in the dry and wet states.

For the PCA-C brackets, a linear regression of the form

SIZE/SLOT = (WIDTH/SLOT)sin θ_c + cos θ_c.

The passive region of the plot consisted of the θ values below the theoretical θ_c and corresponded to the configuration in which clearance existed between the archwire and the bracket; the active region contained the θ values greater than theoretical θ_c and related to the configuration in which clearance no longer existed. Linear regression analyses were applied to the data in the passive and active regions (eg, see Figure 1c). The intersection of the regression lines for the passive and active data defined the experimental θ_c values. For each regression analysis, the probability (P) of the line was determined from the correlation coefficient (r) and the number of data points (n). In the passive region, the classical friction (FR), which equaled RS, was obtained either from the average of the FR values or from the y-axis intercept (b) of the best-fit linear regression line (eg, see Figure 1c). Student’s t-tests were used to compare the different sets of passive data. The differences were considered statistically significant if P ≤ .01 and not significant if P ≥ .1; for .01 < P < .1, the significance of the differences was considered borderline. In the active region, elastic binding (BI) additionally affected the RS value, and was obtained by subtracting FR from RS. To focus on this behavior, the BI values were plotted against the relative angulation (θ_r), which equals θ minus θ_c (eg, see Figure 1d).
To examine any archwire damage that was caused by the PCA-C brackets, four archwires were cut into four pieces each and paired with a bracket. Each archwire piece was tested in the dry state at one of 16 \( \theta \) values: \( 0^\circ, -12^\circ, -10^\circ, -8^\circ, -6^\circ, -4^\circ, -2^\circ, 0^\circ, 2^\circ, 4^\circ, 6^\circ, 8^\circ, 10^\circ, 12^\circ, \) and \( 0^\circ \). The damaged sections of the archwires as well as an untested section were examined using SEM. One of the brackets was coated with carbon and examined using SEM. To determine whether the debris on the edges of the slot walls were SS, elemental analysis was performed using energy-dispersive X-ray analysis at 20 keV (EDX; Thermo Kevex X-Ray, Thermo NORAN, Scotts Valley, Calif).

**RESULTS**

**Dimensions, critical contact angles for binding, and morphologies of the brackets**

The average SIZE of the archwires was 0.4547 mm. The average SLOT size ranged from 0.5334 mm for the PC-C brackets to 0.6172 mm for the SS brackets (Table 2). The PC-C brackets also had the smallest average WIDTH at 3.002 mm (Table 2); the PC-I brackets had the greatest average WIDTH at 3.787 mm. The theoretical \( \theta_c \) ranged from 1.4\(^\circ\) for the PC-I brackets to 2.9\(^\circ\) for the SS brackets (Table 2). All experimental \( \theta_c \) values were within 1.1\(^\circ\) of these theoretical values (Table 2).

The PC-C and PC-I brackets, the PCA-C brackets, and the CRP-I brackets were single brackets (Figure 2); the PCA-I brackets and the CRP-C brackets were true twin brackets. Significant amounts of flash were on the PC-I brackets, even within the slots (Figure 2).

![PC-C](image1.png)

![PCA-C](image2.png)

![CRP-C](image3.png)

![PC-I](image4.png)

![PCA-I](image5.png)

![CRP-I](image6.png)

**FIGURE 2.** Scanning electron micrographs of the conventional polycarbonate (PC-C) brackets, conventional polycrystalline alumina (PCA-C) brackets, and conventional ceramic-reinforced polycarbonate (CRP-C) brackets in the top row and of polycarbonate brackets with SS inserts (PC-I), polycrystalline alumina brackets with SS inserts (PCA-I), and ceramic-reinforced polycarbonate brackets with SS inserts (CRP-I) in the bottom row. See Table 1 for product names and manufacturers and see Table 2 for SLOT and WIDTH dimensions.
FIGURE 3. For the dry state, plot of RS = FR + BI + NO against θ for each bracket design including linear regression lines for the passive configurations (left side of each plot) and the active configurations (right side of each plot). Plots for the conventional esthetic brackets (solid grey line, ---) are in the top row and plots for the esthetic brackets with SS inserts (solid black line, --) are in the bottom row. For the conventional PCA brackets (PCA-C), only data below 4.8° were included in the active region, above which permanent deformation occurred. Note that the linear regression lines (dashed grey line, – - -) for the SS brackets were included for comparison (cf. Figure 1b).

FIGURE 4. For the wet state, corresponding plots and details as those described in Figure 3.

Passive configuration (θ < θ₀)

For both the dry and wet states, the RS values for all esthetic brackets were low (Figures 3 and 4, left side of each plot). In the dry state, the average FR values ranged from 38 cN for the PC-C and SS brackets to 65 cN for the CRP-I brackets (Table 3). The differences between the PCA-C and PCA-I brackets, the PCA-C and SS brackets, the PCA-I and SS brackets, the CRP-C and SS brackets, and the CRP-I and SS brackets were statistically significant (P ≤ .01); those between the PC-C and PC-I brackets and between the PC-I and SS brackets were of borderline significance (.01 < P < .1); those between the PC-C and SS brackets and the CRP-C and CRP-I brackets were not significant (P > .1). In the wet state, the average FR values were generally greater than in the dry state (Table 3); these differences were statistically significant except for the differences between the dry and wet states of the CRP-C brackets and the dry and wet states of the CRP-I brackets. In the wet state, the differences between the PC-C and SS brackets, the PCA-C and PCA-I brackets, the PCA-C and SS brackets, the CRP-C and SS brackets, the CRP-I and SS brackets, and the CRP-I and SS brackets were statistically significant; those between the PC-C and PC-I brackets and between the PC-I and SS brackets were of borderline significance; that between the CRP-C and CRP-I brackets was not statistically significant. For both states, the intercepts (b) were within six cN of the average FR values, and the slopes (m) of the regression lines were near zero, ranging from −6 to +9 cN/m (Table 3). The near-zero m values, low r values, and high P values, despite high n values, indicate that the FR values in the passive configuration were independent of θ values. This should be the case because FR should approximate a constant.

Active configuration (θ ≥ θ₀)

For both the dry and wet states, the RS increased with θ (Figures 3 and 4, right side of each plot). Note the rapid and
TABLE 4. For the Active Configuration, Linear Regression Analyses of Resistance to Sliding Against Angulation for All Brackets

<table>
<thead>
<tr>
<th>Bracket</th>
<th>Slope, m</th>
<th>Intercept, b</th>
<th>r</th>
<th>n</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC-C</td>
<td>16</td>
<td>16</td>
<td>0.89</td>
<td>51</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>PC-I</td>
<td>44</td>
<td>44</td>
<td>0.98</td>
<td>20</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>PCA-C</td>
<td>58</td>
<td>58</td>
<td>0.97</td>
<td>38</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>CRP-C</td>
<td>32</td>
<td>32</td>
<td>0.99</td>
<td>36</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>PCA-I</td>
<td>36</td>
<td>36</td>
<td>0.93</td>
<td>38</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>CRP-I</td>
<td>33</td>
<td>33</td>
<td>0.97</td>
<td>44</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>SS</td>
<td>39</td>
<td>39</td>
<td>0.95</td>
<td>24</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*The linear regression analyses of the form, y = mx + b, in which y was the RS, x was the angulation (θ), m was the slope, and b was the y-axis intercept, were fitted to the active region. The correlation coefficients (r) and the numbers of data points (n) established the probabilities (P). A linear regression was not significant (NS) if the value of P was greater than .05.

For the PC-C brackets, the θ, equaled 4.8°, which was on the basis of the linear regression lines that were fitted to the active data. Examination of the archwires coupled with the PC-C brackets showed that the archwire tested at θ = 8° had several scratches along the surface that had been in contact with the edges of the slot walls (Figure 5a). The archwire tested at θ = 2° and the untested archwire exhibited few scratches on their surfaces. Debris was observed not only along the floor of the PC-C bracket but also on the edges of the walls of the slot (Figure 5b). Although the peaks corresponding to carbon, aluminum, and oxygen were due to the graphite coating and the bracket material (Figure 5c), the peaks of chromium, iron, and nickel represented debris from the SS archwire.

DISCUSSION

Passive configuration (θ < θc)

Because only FR contributes to RS in the passive configuration, the kinetic coefficient of friction (μk-FR) equals the ratio of the measured FR to the applied normal force (300 cN). For the dry and wet states, the esthetic brackets with SS inserts often have average FR values, and thus μk-FR values, that are less than or equivalent to the conventional esthetic brackets (Table 3, column 3 and 4; Figure 6). Consequently, the frictional properties of the brackets with SS inserts are generally between the conventional esthetic and the control SS brackets. A study of the same PCA-I brackets reported similar μk-FR values in the dry state but greater values in the wet state than observed herein. Although the materials of the couple should govern the results, these brackets with SS inserts do not generally mimic the SS brackets.

In clinical terms, all esthetic brackets can, at best, approach the μk-FR of the SS brackets, although the values may be much greater, too (Table 3). For the PC-C brackets, note that the μk-FR value in the dry state is much lower than in the wet state. This is attributed to the greater wettability of PC than the other materials studied. Because greater values of critical surface tension correspond to greater wettabilities, the critical surface tension of PC is 45 mN/m, followed by SS and CRP at 41 mN/m, and PCA at 29 mN/m. The increased critical surface tension appears to correlate with increased differences between μk-FR values in the dry and wet states (Table 3). Nonetheless, one study reported greater FR values in the dry state for PC-C brackets than SS brackets, although specific product names were not provided. The PC-C brackets are generally accepted to have greater FR values than SS brackets. In contrast, according to Berger, the FR values of both CRP-C and SS brackets varied widely, and no consistent trend was observed. Direct comparisons of FR values between studies generally cannot be made without knowing the normal forces, the ligation methods, and the second-order angulations. Additionally, artificial saliva produces different results than whole fresh human saliva, both in absolute magnitude and relative rankings.
FIGURE 5. After frictional testing in the dry state, the PCA-C brackets and their associated archwires were examined. (a) Digitally enhanced scanning electron micrographs of an untested archwire and two archwires after testing at $\theta = 2^\circ = \theta_c$ and at $\theta = 8^\circ > \theta_c$; the double arrow indicates the long axes of the archwires. (b) Scanning electron micrographs of the slot morphology at two magnifications. (c) X-ray energies produced by the debris on the leading edge of the slot (foreground) as shown in the micrographs. Although not shown, debris on the trailing edge of the slot produced the same spectral peaks.

FIGURE 6. For the passive configuration, plots of $\theta$ vs $FR = RS$ in the dry state (top row) and the wet state (bottom row). The plots for each bulk material include the data for the esthetic brackets with (solid black line, —) and without (solid grey line, —) SS inserts and the SS brackets (dashed grey line, ——) (cf. Figure 1c).

**Active configuration ($\theta \geq \theta_c$)**

Elastic binding (BI) increasingly contributes to RS as $\theta$ increases above $\theta_c$. Because the $m$ values (in other words, the coefficients of binding $[\mu_{BI}]$) of these linear regression lines for BI against $\theta$, in the active configuration depend on material and geometric factors, these factors and the interbracket distances were controlled so that any changes in the $m$ values were only attributable to the designs and materials of the brackets. Except for the PC-C brackets in the dry state, the $m$ values of the esthetic brackets with and without SS inserts were comparable with or exceeded those of the SS brackets in both states (Figure 7). For the PC-C brackets, the $m$ value was lower in the dry than in the wet state (Table 4, column 3). Although this low $m$ value may indicate deformation of the PC-C brackets in the dry state, no morphological evidence of permanent deformation was observed after RS measurements were completed (not shown). Consequently, we postulated that the PC material elastically deformed, thereby somewhat conforming to the imposed angulation and reducing the RS values. When movement of the tie-wings was inhibited, the $m$ values for both states were greater than when the tie-wings were unsupported (Figure 8). This indicated that the tie-wings did indeed elastically deform. The addition of SS inserts to the PC brackets apparently prevented such elastic deformation by strengthening the bracket (Figure 7). Similarly, the addition of ceramic particles to the PC matrix of the CRP-C brackets also appears to prevent elastic deformation, as little difference was observed between the CRP-C brackets in which the tie-wings were supported and those in which the tie-wings were unsupported (Figure 8).
FIGURE 7. For the active configuration, plots of \( \theta = \theta - \theta_0 \) vs BI = RS - FR in the dry state (top row) and the wet state (bottom row). The plots for each bulk material include the data for the esthetic brackets with (solid black line, \( \theta \)) and without (solid grey line, \( \theta \)) SS inserts and the SS brackets (dashed grey line, ---) (cf. Figure 1d).

FIGURE 8. For the dry state (top row) and the wet state (bottom row), plots of \( \theta \) vs RS = FR + BI for the PC-C and CRP-C brackets in which the tie-wings were supported (solid black line, \( \theta \)) to inhibit any deformation and in which the tie-wings were unsupported (solid grey line, \( \theta \)). For the PC-C brackets in the active configuration (right side of each plot in left column), the decreased rates of BI when the tie-wings were unsupported were attributed to elastic deformation of the tie-wings. Such deformation was not apparent for the CRP-C brackets (right side of each plot in right column). For convenience, the data for the unsupported brackets are reproduced from Figures 3 and 4.

As previously noted for the PCA-C brackets, the RS values for \( \theta \) values above \( \theta_0 \) increased rapidly and nonlinearly (Figures 3 and 4, right side of the plots for PCA-C brackets). Notching of archwires occurs whenever the applied stress exceeds the yield strength of a material. Notches have been found along archwires after their clinical use but had not previously been documented during in vitro frictional testing. Although the damage to the archwires tested in vitro was not as severe as in vivo, scratches on the surface of these archwires appeared to be more severe at \( \theta \) values above \( \theta_0 \) than below \( \theta_0 \) (Figure 5a). The scratchs along the sides of the archwires that were in contact with the slot walls may be the precursors to the types of notches observed in posttreatment archwires. Debris, consisting mainly of SS (Figure 5c), was found on the leading edges of the slot walls (Figure 5b) as well as on the trailing edges (not shown). Because such material was observed on the outside of the slot, the brackets must have been angulated relative to the archwire when the material was removed.

Because the archwire-bracket combination is under a more complex and demanding stress state in vivo than in vitro, more damage can occur. These complex forces can create a triaxial state of stress in the archwires and the brackets, which reduces the apparent maximum stress at which the archwire permanently deforms as compared with the yield stress in uniaxial tension. As the understanding of the forces that are produced within the archwire-bracket couples during both binding and notching is improved, the responses of the archwires and brackets, including elastic and permanent deformations, will be better predicted.

CONCLUSIONS

When clearances existed, the frictional properties of esthetic brackets with SS inserts were between those of SS brackets and those of conventional esthetic brackets.

When clearances no longer existed, the rates of binding of esthetic brackets with and without SS inserts (except for the conventional PC bracket in the dry state) were comparable with or greater than those of the SS brackets. The conventional PC brackets in both the dry and wet (saliva) states elastically deformed when they interacted with the relatively rigid archwire. The addition of SS inserts apparently inhibited the elastic deformation of PC brackets.

When clearances no longer existed and the conventional PCA brackets were at large second-order angles relative to the archwires, the resistances to sliding increased more rapidly than those of any other bracket. Scratches from the slot walls along the surfaces of the archwires and SS debris on the leading and trailing edges of the brackets’ slot walls indicated permanent deformation of the archwires by the PCA brackets.

The addition of SS inserts to esthetic brackets generally did not reduce the RS to that of SS. The SS inserts, however, did improve the strength and rigidity of PC brackets. Furthermore, unlike conventional PCA brackets, the PCA brackets with SS inserts did not exhibit a rapid increase in RS at large second-order angulations.

*A triaxial state of stress, which is also called a three-dimensional state of stress, is defined by the three principal stresses (which are the maximum normal stresses in a coordinate system in which no shearing stresses exist) acting at a point within a body.
APPENDIX

Appliance dimensions

For the PCA and SS brackets, the occlusogingival SLOT dimension of each bracket was measured three times on each side for a total of six measurements using the optics of a Kentron microhardness tester (Kent Cliff Labs, Peekskill, NY). The mesiodistal WIDTH dimension of each of these brackets was measured three times using Starrett calipers (L.S. Starrett Co, Athol, Mass). For the PC and CRP brackets, the SLOTS and WIDTHs were measured for 20 of the 128 brackets of each design that were tested. The occlusogingival SIZE dimension of the archwire was measured at five different locations on each wire using a micrometer (Sony μ-mate, Sony Magnescale America Inc, Orange, Calif).

Mounting procedure

The brackets were mounted on SS cylinders such that the effects of the prescription were eliminated. The archwires were mounted in brass collets and were attached to a calibrated load cell, which measured the drawing forces.

Saliva viscosity

A cone-and-plate viscometer (Brookfield Model LVTDV-II CP, Brookfield Engineering Laboratories Inc, Stoughton, Mass) was used to characterize the operator’s saliva. The viscosity of this saliva was within the normal range of 1.3–2.0 centipoise at 34°C.

REFERENCES