A Comparative Evaluation Of Frictional Resistance Of Conventional, Teflon And Epoxy Coated Stainless Steel Archwires In Ceramic Brackets And Passive Self-Ligating Brackets – An Invitro Study

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Aims & Objectives: To evaluate frictional resistance of Conventional, Teflon, and Epoxy coated stainless steel arch wires in Ceramic brackets and Self-ligating brackets.

Materials and Methods: The wires are cut into 5cm long and are ligated to bracket using 0.010- inch ligature wire. Acrylic block is placed in lower arm of Instron™ universal testing machine so that it will hold the block while performing a frictional test. Free end of wire is pulled with upper arm of universal testing machine, at a rate of 10 mm/ min while the wire is placed parallel to long axis of bracket and tooth, and a load of 50 kg was used to measure frictional forces.

Results: Ceramic bracket combined with SS arch wire showed frictional mean value is 6.529N. The ceramic bracket combined with Epoxy coated Arch wire showed mean value is 9.3305N. The Ceramic bracket combined with Teflon coated Arch wire showed mean value is 5.3483N. The SS self-ligating bracket combined with SS arch wire showed mean value is 1.7675N. The SS self-ligating bracket combined with Epoxy coated Arch wire mean value is 8.5539N. The SS self-ligating bracket combined with Teflon coated Arch wire mean value is 2.298N.

Conclusions: Self-ligating brackets combined with stainless steel arch wires or Teflon coated arch wires may be used effectively in sliding mechanics, rather than ceramic brackets and tooth-colored epoxy coated arch wires.
INTRODUCTION:
Friction is classically described as a force acting tangentially at surface of two moving bodies in contact. Friction acts parallel to and opposing the movement. Friction can be either static or kinetic. Static friction is the force needed to start the movement, whereas kinetic friction is force required to maintain movement once started. Frictional forces in clinical orthodontics are considered as a primary concern since it resists regular tooth movements. During sliding movements of teeth, wire edges contact the bracket angles, and a frictional force will develop that compete with normal tooth movements and decrease the magnitude of applied orthodontic forces.

Orthodontic treatment used with sliding mechanics involves a relative displacement of wire through bracket slots, and whenever sliding occurs, frictional resistance will arise. During early alignment phase, when all teeth move at same time, low levels of friction is required for the wire to slide through 10 brackets and two tubes. Ceramic brackets were developed to improve aesthetics during orthodontic treatment. However, they have problems such as brittleness leading to bracket or tie-wing failure, iatrogenic enamel damage during debonding, and high frictional resistance to sliding mechanics. Ceramic brackets with stainless steel slot were recently developed to combine the frictional characteristics of stainless steel with aesthetics of ceramics.

Self-ligating brackets were introduced in mid-1930s in the form of Russell attachment. Self-ligating brackets are ligature less bracket systems. They are classified into 2 main categories, those in which self-ligating clip does not press against arch wire ("passive" self-ligating brackets), those with a spring clip that presses against arch wire ("active" or "interactive" self-ligating brackets). Passive self-ligating brackets induce less friction during sliding mechanics than active self-ligating brackets.

So, an orthodontist must apply more force to overcome friction, which results in increased anchorage loading and subsequent anchorage loss. This concept has motivated to seek techniques to reduce friction and, consequently, reduce the demand on anchorage and more efficient the system to achieve optimum goals.

AIMS AND OBJECTIVES
The objectives of study are to evaluate frictional resistance of,
A) 0.019” x 0.025” Conventional stainless steel arch wires (G & H™).
B) 0.019” x 0.025” Teflon coated stainless steel arch wire (D-Tech™).
C) 0.019” x 0.025” Epoxy-coated stainless steel arch wire (G & H™). In
D) Ceramic brackets (Gemini clear - 3M Unitek™, Monrovia, California, USA),
E) Self-Ligating passive brackets (Empower2™-American Orthodontics, USA),

MATERIALS: -
1) 0.019” x 0.025” Stainless steel arch wire. (G & H™) – 30n
2) 0.019” x 0.025” Teflon coated stainless steel arch wire. (D-Tech™) - 30n
3) 0.019” x 0.025” Epoxy-coated stainless steel arch wire. (G & H™) - 30n
4) 0.22 MBT Ceramic (Gemini- 3M Unitek™) lower incisor brackets - 30n
5) 0.22 MBT Passive Self-ligating (Empower2™) lower incisor brackets - 30n

METHODOLOGY
A total of 60 acrylic lower incisor typodont teeth are used in study. Using silicon rubber impression material (MoldSil 15™), a rectangular mould was prepared, then cold cure acrylic powder and liquid (DPI) is poured into the mould to make rectangular acrylic blocks in which acrylic lower incisor typodont tooth is embedded vertically up to neck of tooth. Individual orthodontic lower incisor brackets were glued to lower incisor acrylic typodont tooth which are mounted in acrylic block using glue adhesive, (Cyanoacrylate™), in a standardized manner, so that long-axis of test bracket slot was parallel to upper arm of Instron™ universal testing machine. (Figure 1)

Wires are cut into 5cm long and are ligated to bracket using 0.010-inch ligature wire. Acrylic block is placed in lower arm of Instron™ universal testing machine so that it will hold the block while performing a frictional test.
Free end of wire is pulled with upper arm of universal testing machine, at a rate of 10 mm/min while the wire is placed parallel to long axis of bracket and tooth, and a load of 50 kg was used to measure frictional forces. Based on line graph obtained from the movement of wire in the bracket, average of highest recorded point on line graph was considered as static friction. Total procedure was repeated for all specimens of respective groups. Total number of groups were as follows.

**Composition of test groups:**

*Group 1:* Ten Ceramic brackets (Gemini clear - 3M Unitek™, Monrovia, California, USA) with 0.019”x 0.025” Conventional stainless steel (G & H™) arch wires were used for testing. (Figure 2)

*Group 2:* Ten Ceramic brackets (Gemini clear -3M Unitek™, Monrovia, California, USA), with 0.019”x 0.025” Epoxy-coated stainless steel arch wire (G & H™) were used. (Figure 3)

*Group 3:* Ten Ceramic brackets (Gemini clear -3M Unitek™, Monrovia, California, USA) with 0.019”x 0.025” Teflon coated stainless steel arch wires (D-Tech™) were used. (Figure 4)

*Group 4:* Ten Self-Ligating passive brackets (Empower2™- American Orthodontics, USA) with 0.019”x 0.025.” Conventional stainless steel arch wires (G & H™) were used. (Figure 5)

*Group 5:* Self-Ligating passive bracket (Empower2™- American Orthodontics, USA) with 0.019” x0.025” Epoxy-coated stainless steel arch wires (G & H™) were used. (Figure 6)

*Group 6:* Ten Self-Ligating passive bracket (Empower2™- American Orthodontics, USA) with 0.019”x 0.025.” Teflon coated stainless steel (D-Tech™) arch wires were used. (Figure 7)
Figure 3: Ceramic bracket with Epoxy coated 0.019” x 0.025” SS archwire

Figure 4: Ceramic bracket with Teflon coated 0.019” x 0.025” SS archwire

Figure 5: Self-ligating bracket with Uncoated 0.019” x 0.025” SS arch wire
STATISTICAL ANALYSIS:
Data collected is entered into a computer and analysed using SPSS software. Results on continuous measurements are presented on Mean + SD, results on categorical measurements are presented in number (%). Level of significance is fixed at p=0.05, and any value equal to or less than or <0.05 is considered statistically significant. One way ANOVA and Tukey test is used to determine significant frictional differences between arch wires and brackets.

RESULTS
The observations are as summarized below in table 1 & table 2. Ceramic bracket with epoxy coated ss arch wire shows highest frictional resistance, i.e. 9.330N, whereas Self-ligating bracket + ss arch wire shows lowest frictional resistance of 1.767N.
Table 1: Descriptive statistics for groups

<table>
<thead>
<tr>
<th>BRACKET TYPE</th>
<th>ARCHWIRE TYPE</th>
<th>MEAN (SD)</th>
<th>MINIMUM</th>
<th>MAXIMUM</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic Bracket</td>
<td>0.019” X 0.025” stainless steel</td>
<td>6.529 (1.6081)</td>
<td>5.622</td>
<td>10.307</td>
<td>6.200-8.501</td>
</tr>
<tr>
<td>Self- Ligating Bracket</td>
<td>0.019” X 0.025” stainless steel</td>
<td>1.767 (1.1400)</td>
<td>1.661</td>
<td>5.958</td>
<td>2.978-4.609</td>
</tr>
<tr>
<td>Ceramic Bracket</td>
<td>0.019” X 0.025” Epoxy coated SS</td>
<td>9.330 (2.4077)</td>
<td>5.622</td>
<td>14.881</td>
<td>7.608-11.052</td>
</tr>
<tr>
<td>Self- Ligating Bracket</td>
<td>0.019” X 0.025” Epoxy coated SS</td>
<td>8.553 (0.7268)</td>
<td>4.315</td>
<td>9.823</td>
<td>4.828-10.868</td>
</tr>
<tr>
<td>Ceramic Bracket</td>
<td>0.019” X 0.025” Teflon coated SS</td>
<td>5.348 (1.2302)</td>
<td>5.960</td>
<td>10.315</td>
<td>7.673-9.433</td>
</tr>
<tr>
<td>Self- Ligating Bracket</td>
<td>0.019” X 0.025” Teflon coated SS</td>
<td>2.298 (0.6141)</td>
<td>1.243</td>
<td>3.299</td>
<td>1.858-2.737</td>
</tr>
</tbody>
</table>

SD - Standard deviation; CI – Confidence interval for mean

Table 2: Pairwise comparisons between groups, using Post hoc Tukey test

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean difference</th>
<th>P</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic + SS - Ceramic + Epoxy</td>
<td>2.802</td>
<td>P &lt; 0.0001</td>
<td>0.7648 to 4.8382</td>
</tr>
<tr>
<td>Ceramic + SS - Ceramic + Teflon</td>
<td>-1.181</td>
<td>P &lt; 0.0002</td>
<td>-2.5307 to 0.1693</td>
</tr>
<tr>
<td>Ceramic + SS - Self-ligating+ SS</td>
<td>-4.762</td>
<td>P &lt; 0.0001</td>
<td>-6.1727 to -3.3503</td>
</tr>
<tr>
<td>Ceramic + SS - Self-ligating +Epoxy</td>
<td>2.025</td>
<td>P &lt; 0.0011</td>
<td>0.5225 to 3.5273</td>
</tr>
<tr>
<td>Ceramic + SS - Self-ligating +Teflon</td>
<td>4.231</td>
<td>P &lt; 0.0001</td>
<td>-5.5560 to -2.9060</td>
</tr>
<tr>
<td>Ceramic + Epoxy - Ceramic +Teflon</td>
<td>-3.982</td>
<td>P &lt; 0.0001</td>
<td>-5.6531 to -2.3113</td>
</tr>
<tr>
<td>Ceramic + Epoxy - Self-ligating +SS</td>
<td>-7.563</td>
<td>P &lt; 0.0001</td>
<td>-9.2837 to -5.8423</td>
</tr>
<tr>
<td>Ceramic + Epoxy - Self-ligating + Epoxy</td>
<td>-0.777</td>
<td>P &lt; 0.0003</td>
<td>-2.5729 to 1.0197</td>
</tr>
<tr>
<td>Ceramic + Epoxy - Self-ligating +Teflon</td>
<td>-7.033</td>
<td>P &lt; 0.0001</td>
<td>-8.6833 to -5.3817</td>
</tr>
<tr>
<td>Ceramic + Teflon – Self-ligating+ SS</td>
<td>-3.581</td>
<td>P &lt; 0.0001</td>
<td>-4.3779 to -2.7837</td>
</tr>
<tr>
<td>Ceramic + Teflon – Self-ligating+ Epoxy</td>
<td>3.206</td>
<td>P &lt; 0.0001</td>
<td>2.2563 to 4.1549</td>
</tr>
<tr>
<td>Ceramic + Teflon – Self-ligating +Teflon</td>
<td>-3.050</td>
<td>P &lt; 0.0001</td>
<td>-3.6825 to -2.4181</td>
</tr>
<tr>
<td>Self-ligating + SS - Self-ligating + Epoxy</td>
<td>6.786</td>
<td>P &lt; 0.0001</td>
<td>5.7519 to 7.8209</td>
</tr>
<tr>
<td>Self-ligating + SS – Self-ligating+ Teflon</td>
<td>0.531</td>
<td>P &lt; 0.0001</td>
<td>-0.2236 to 1.2846</td>
</tr>
<tr>
<td>Self-ligating + Epoxy -Self-ligating+ Teflon</td>
<td>-6.256</td>
<td>P &lt; 0.0001</td>
<td>-7.1694 to -5.3424</td>
</tr>
</tbody>
</table>
DISCUSSION

Friction is defined as a force which resists or delays or the relative motion of two objects which are in contact and its direction is tangential to common interface of the two surfaces. Frictional force is proportional to applied load under normal conditions, depending on nature of sliding surfaces and independent of contact area between the surfaces and sliding speed. Friction coefficient of a given material couple is the ratio between tangential force (frictional force) and the normal or perpendicular load applied during the relative motion.1

In fixed orthodontic therapy, teeth are moved using sliding mechanics or retraction Arch wires involving minimal friction, in which friction is notably large. Friction is a factor in sliding mechanics, such as during active torque, retraction of teeth into an extraction area, levelling and alignment, when Arch wire must slide through bracket slots and tubes.2,3 During sliding mechanics, tissues response and tooth movement occur only when forces are applied exceeds the friction on bracket wire interface. High levels of frictional force result in debonding of bracket, associated with either a small dental movement or no movement and possibly anchor loss. When friction prevents movement of teeth to which the bracket is attached, friction can reduce the available force by 40%, resulting in an anchorage loss.3

There are different techniques to measure frictional resistance between bracket and Arch wire, such as dynamometer, a weighed basket, force measuring gauge and universal testing machine. Literature revealed that friction between bracket and Arch wire is multifactorial and different authors mentioned that frictional resistance increases or vary by different factors such as bracket material, wire size, the difference in wire material, angulation of wire to the bracket, method of ligation. However, there are different conflicting views on influence of factors on friction, such as surface roughness, bracket width, lubrication, ligature design, and arch shape.

In our study, highest frictional resistance was recorded with 0.019” x 0.025” Epoxy coated arch wire surface with ceramic brackets (9.33N). This combination resulted in a marked increase in static friction over most efficient combinations among the study groups. Self-ligating brackets were associated with significantly less static friction (1.767N) than ceramic brackets in combination of arch wires used in our study. Largest difference was noted with 0.019” x 0.025” Epoxy coated arch wires than other arch wires with all type of brackets used in our study. With respect to arch wire alloys, stainless steel arch wires had a significantly lower coefficient of static friction than Epoxy coated and Teflon coated wires in agreement with several previous studies.

According to Syed Altaf Khalid et al.7 round wires produced less friction than rectangular wires. Orthodontist uses 0.019” x 0.025” SS wire during retraction of tooth, which has more friction when compared to round wires. Results from static frictional coefficients may have a greater significance to slow and non-continuous tooth movement observed with sliding mechanics. There are numerous factors associated such as arch form, type of arch wire alloy, bracket material, bracket type (self-ligation or conventional) and testing environment that influence the frictional resistance.

Zacharias et al compared effect of dental arch convexity and flat model setup on frictional forces. They explained that frictional forces are higher with convex arch form than with a straight model. Taylor and Ison mentioned that any residual curves in wire influence the friction generated. In our study, brackets were glued to buccal segments of acrylic lower incisor typodont tooth. By this setup, we can measure frictional forces more effectively and can avoid errors created by using linear model step up. Based on classic laws of friction, static9,10 be larger than corresponding kinetic coefficient of friction is important to know static friction of bracket and arch wire to initiate tooth movement.

The influence of bracket material plays a crucial role in friction resistance. According to Prattern et al., intrinsic chemical nature, increased roughness and porosity of ceramic surfaces and a sharp bracket slot edge, creates a higher coefficient of friction. Scanning electron microscope studies showed that ceramic brackets display a crystalline structure containing many pores. Still, stainless steel brackets slot are smoother with fewer irregularities. 12 Saunders and Kusy explained by scanning electron microscopy...
study that monocrystalline alumina brackets are smoother than polycrystalline brackets. The friction created by polycrystalline bracket was higher than friction produced by monocrystalline brackets. Greater force is required to overcome interlocking of asperities with the arch wire. Influence of arch wires alloy will play an essential role on friction. Studies by Andreasen and Quevedo. Frank et al.14 and Drescher et al15 showed a general tendency for level of frictional resistance to increase with increasing wire size. Stiffer wire produced a greater component of contact force between itself and bracket-slot base and self-ligating clip/gate, resulting in a much larger frictional resistance magnitude. Arch wire relative to bracket or bracket relative to arch wire with approximated zero tip and torque, does not permit tipping of bracket relative to arch wire indicating that no binding interaction at edges of bracket-arch wire interface will occur. This non-binding sliding demonstrated that frictional resistance increases respectively with arch wire selections of stainless steel, Epoxy coated ss, nickel-titanium, and Teflon coated arch wires.

Influence of self-ligation has an impact on friction. Our study demonstrated that self-ligating brackets produced low static friction than ceramic brackets. Randomized control trials and systemic review concluded that efficiency and treatment out come in terms of quality and time. Self-ligating brackets not superior to conventional brackets systems, no evidence of reduction of friction in self-ligating brackets. Miles et al. analysed efficiency of ceramic self-ligating and conventional Ceramic Brackets during initial alignment stage 16. Results shown that there is no difference in rate of alignment between the two.

Iwasaki et al 17 calculated that 31-54% of total frictional force generated by a premolar bracket moving along 0.019×0.025 stainless steel arch wire was due to friction of ligation and the remaining 46-69% was due to elastic binding. So ligation is considered as an established parameter affecting the resistance to applied forces.

According to Harradine18 “Damon system” had better outcome in treatment time, shortening the total duration to months less than the conventional system. According to Scott et al, a randomized controlled trial showed that, with respect to clinical efficacy during tooth alignment, there was no difference between self-ligating and conventional systems. Study by Redlich et al 19 on five different brands of "reduced friction" claiming brackets showed that there was no such "reduced friction" as claimed by the manufacturers. Friction between bracket and wire is present from early stages of alignment and levelling up to finishing phase. Thus, resistance to sliding of bracket along the orthodontic wire is important in clinical practice since lower friction of orthodontic mechanics can be directly related to a reduction in treatment time. In present study, ligature wire is used instead of elastomeric ligatures in order to standardize force magnitude.

Maximum static friction appeared with coated wires than uncoated wires since they have larger width due to additional coating layer which is about 1.0 to 1.4 mm. Researchers investigated that frictional forces of aesthetic orthodontic wires focused on link with surface roughness of the coating layer of coated arch wires. Rhodium and Teflon coating materials are most common surface treatment used to coat stainless steel and nickel-titanium orthodontic arch wires and rhodium coated types have increased surface roughness and consequently increased friction while Teflon coated wires have a smoother surface and showing least amount of friction thus improved sliding movements will be obtained. 21

The self-ligating mechanism is broadly classified into an active and passive types based on their clip or lock mechanism. In passive type, clip creates a passive labial surfacede slot with no encroach of clip to the slot; Generic advantages claimed for these brackets by various companies are a secure active or passive ligation mechanism providing consistent full bracket wire - engagement, reduces friction between Arch wire and bracket, and this provides rapid tooth movement and excellent control of tooth position by an adequately dimensioned bracket (Nigel Harradine 2008).

In this present study, self-ligating brackets showed lesser frictional resistance when combined with Teflon and stainless steel arch wires, but when combined with Epoxy coated Arch wire, showed high frictional resistance. Generally, friction increases with increase of arch wire diameter according to Angolkar et al. 22
CONCLUSION
Within the limitations of present study, following conclusions can be drawn. Among all test groups, Ceramic bracket exhibited highest frictional resistance. Self-ligating brackets showed lower frictional resistance when compared to other groups. 0.019" x 0.025" Epoxy coated SS arch wire showed the highest friction whereas 0.019" x 0.025" stainless steel arch wire showed the lowest friction. Hence self-ligating brackets combined with stainless steel arch wires or Teflon coated arch wires may be used effectively in sliding mechanics, rather than ceramic brackets and tooth-colored epoxy coated arch wires.

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