Archwire cleaning after intraoral ageing: the effects on debris, roughness, and friction

David Normando*, Adriana Monteiro de Araújo*, Isabella da Silva Vieira Marques*, Carmen Gilda Barroso Tavares Dias** and José Augusto Mendes Miguel***

Departments of *Orthodontics and **Mechanical Engineering, Federal University of Pará and ***Department of Orthodontics, State University of Rio de Janeiro, Brazil

Correspondence to: David Normando, Rua Boaventura da Silva, 567-1201, Belém, Pará 66055-090, Brasil.
E-mail: davidnor@amazon.com.br

SUMMARY Dental material science has paid more attention to mechanical properties of as-received materials than to changes produced after intraoral exposure. Orthodontic archwires when exposed to the intraoral environment have shown a significant increase in the degree of debris, surface roughness (Ra), and frictional force. The purpose of this split-mouth study was to evaluate the effects of two methods of archwire cleaning on these variables after clinical use for 8 weeks. For eight individuals, four sets of three brackets each (n = 32) were bonded from the first molar to the first premolar. A passive segment of 0.019 × 0.025 inch stainless steel (SS) archwire was inserted into the brackets and tied by elastomeric ligature. Debris level [via scanning electron microscopy (SEM)], Ra, and frictional force were evaluated in a paired comparison after 8 weeks of intraoral exposure and after cleaning with a steel wool sponge (SWS) for 1 minute or ultrasound (US) cleaning for 15 minutes. Kruskal–Wallis, Friedman’s, and Spearman and Pearson correlation tests were used for statistical analysis.

The debris and Ra of SS rectangular wires increased significantly (P < 0.05) during clinical use, causing a significant increase in the frictional force level. These changes can be effectively eliminated by either of the investigated cleaning methods, although a SWS seems to be clinically more practical.

Introduction

Friction is defined as a force that retards or resists the relative motion of two surfaces in contact, and its direction is tangential to the common boundary of both. There are two distinct types of friction: static and kinetic. Initially, static friction must be overcome to start moving the tooth and then when the tooth is moved, kinetic friction occurs and the archwire moves in the direction of the applied force (Fernandes et al., 2005; Kuramae, 2006).

The influence of friction between the wire and bracket during tooth movement in orthodontic treatment is of interest since many techniques involve mechanical sliding. During orthodontic mechanotherapy, tooth movement occurs only when the applied forces overcome the friction at the bracket–wire interface, the so-called effective force (Rossouw, 2003). Therefore, it is important to know the force level of the system because if frictional forces are higher than the applied force, the efficiency of the system is affected, and the treatment time may be extended or the outcome compromised due to the little or no tooth movement and/or loss of anchorage (Kuramae, 2006). It has been shown that the frictional force between the bracket and wire can result in the loss of up to 50 per cent of the orthodontic force applied (Drescher et al., 1989; Wichelhaus et al., 2005).

Several mechanical (Frank and Nikolai, 1980; Drescher et al., 1989; Kapila et al., 1990; Kusy and Whitely, 1990; Bednar et al., 1991; Thorstenson and Kusy, 2001; Mendes and Rossouw, 2003; Rossouw, 2003; Fernandes et al., 2005; Kuramae, 2006; Tecco et al., 2007; Whitley and Kusy, 2007; Kim et al., 2008; Franchi et al., 2008) and biological (Drescher et al., 1989; Kusy and Whitley, 2000; Thorstenson and Kusy, 2001, 2002; Smith et al., 2003; Franchi et al., 2008) variables may modify the frictional force generated during mechanical sliding. Dental material science has paid more attention to archwire mechanical properties of as-received materials than to changes produced after intraoral exposure (Kusy and Whitley, 2000; Eliades and Bouraupel, 2005). Only a few investigators have evaluated the effect of clinical use on orthodontic archwires (Eliades and Bouraupel, 2005). These studies showed a significant increase in the amount of surface roughness (Ra; Eliades and Athanasiou, 2002; Daems et al., 2009) and frictional force correlated to Ra (Wichelhaus et al., 2005; Marques et al., 2010).

Although orthodontic nickle–titanium (NiTi) archwires are commonly used, stainless steel (SS) archwires are more frequently indicated for sliding mechanics because of their lower friction coefficients (Drescher et al., 1989; Kapila et al., 1990; Kusy and Whitley, 1990; Mendes and Rossouw, 2003). Rectangular SS archwires used during sliding mechanics may also need to stay in the oral environment for several months. A recent investigation (Marques et al., 2010) found...
that SS rectangular wires, when exposed to the intraoral environment for 8 weeks, showed a significant increase in the degree of debris, surface Ra, and frictional force. Those authors observed a significant correlation between the amount of debris and friction and suggested that research is needed to evaluate the efficiency of methods employed to clean orthodontic archwires.

The aim of this investigation split-mouth was to determine the effects of two methods of archwire cleaning after clinical use. Specifically, the changes in the degree of debris impregnated on the orthodontic wire, the wire surface Ra, and the friction produced during sliding were evaluated.

**Materials and methods**

This study was approved by the Commission of Bioethics, Faculty of Dentistry of the Brazilian Federal University, Pará State 025/2008. Consent was also sought by asking subjects to sign a form that explained the nature and purpose of the investigation.

The sample size was calculated by the use of paired parametric statistical analysis of the friction differences between the control (T1) and post-cleaning (T2) sides. A power of 80 per cent was assumed to detect a difference of 0.75 N of force and standard deviation of the difference 0.6 N (Marques et al., 2010) and a bilateral alpha level of 5 per cent. The sample size was determined to be equal to seven pairs.

The effects of intraoral exposure and archwire cleaning were examined in eight adults (four males and four females). Bonding consisted of a set of three edgewise brackets, slot 0.022 × 0.030 inch (Morelli, São Paulo, Brazil) in each hemiarch (n = 32), from the first molar to the first premolar. A straight segment of as-received (T0) SS wire, 0.019 × 0.025 inch (3M Unitek, St Paul, Minnesota, USA), was inserted into each of the 32 sets of brackets. The wires were carefully tied to the brackets with elastic ligatures (diameter 0.120 inch; Unicycles; Masel, Carlsbad, California, USA). The sets of brackets, ligatures, and wires remained in the oral environment for 8 weeks (Figure 1).

After intraoral exposure, the segments of wire (n = 32) were randomly assigned into pairs. In one unit of these pairs, a cleaning method was implemented, while the other component of the pair was used as the control (no cleaning). Two cleaning methods were examined, generating groups of eight pairs of wire segments for each method (T2). In the first group, one wire of each pair was cleaned with a steel wool sponge (SWS), Bombril® (São Bernado do Campo, São Paulo, Brazil) by rubbing for 1 minute (Figure 2). In the second group, one wire of each pair was subjected to cleaning by ultrasonic (US), for 15 minutes immersed in a solution containing distilled water and enzyme detergent (Riozyme III, São José do Rio Preto, São Paulo, Brazil), according to the instructions and proportion set by the manufacturer.

The debris level and Ra were evaluated at T0, T1, and T2 after SWS rubbing or US immersion, using a longitudinal paired design. Because of the surface changes produced in the orthodontic wires after friction testing, friction was evaluated by a transverse paired design. Five segments of as-received wires were used to perform the control friction test and five other as-received wires to determine friction after SWS rubbing. Thus, these wires were not used clinically. The other 32 wires were subjected to friction evaluation at T1 and T2 (after cleaning). All examinations were performed within 48 hours of removal of the wires from the oral environment.

**Scanning electron microscopy and Ra analysis**

For the microscopic debris and Ra analyses, the upper tip of each segment of the wire was fixed on a glass slide. A mark in the central area of the wire had been determined previously in order to standardize the reading. The central area (0.025 inch) of the wires was observed by scanning electron microscopy (SEM) using the LEO 1430 microscope (Carl Zeiss, Jena, Germany), and images were obtained from secondary electrons, with magnifications of ×18 and ×200.

Assessment of the amount of debris on the surface of the wires was performed by a single examiner (DN). The following scores were used, according to previously published methods used in endodontics (Van Eldik et al., 2004; Drukeinis and...
Bonding consisted of a set of three edgewise brackets, slots were examined in eight adults (four males and four females).  

et al.

et al.

between the control (T1) and post-cleaning (T2) sides. Parametric statistical analysis of the friction differences

Faculty of Dentistry of the Brazilian Federal University,

Materials and methods

impregnated on the orthodontic wire, the wire surface Ra, the effects of two methods of archwire cleaning after clinical

clean orthodontic archwires. The aim of this investigation split-mouth was to determine the degree of debris, surface Ra, and frictional force. Those SS rectangular wires, when exposed to the intraoral

remained in the oral environment for 8 weeks (Figure 1).

Two cleaning methods were examined, generating groups of wires. For the microscopic debris and Ra analyses, the upper tip of each wire was observed by transverse paired design. Five segments of as-received (T0) SS wire, after SWS rubbing or US immersion, using a longitudinal microscope (Carl Zeiss, Jena, Gemany), and images were obtained from secondary electrons, with magnification ×18, ×200. SEM examination

The data distribution for Ra and friction were checked with the Shapiro–Wilk test. Ra comparison at T0, T1, and T2 was evaluated by analysis of variance (ANOVA), while debris level was examined by Friedman’s ANOVA. Because friction was not normally distributed at T1–SWS (P = 0.01) and there was an unequal variance for the US groups, Kruskal–Wallis analysis and Dunn’s post hoc test was used to examine friction differences between T0, T1, and T2.

For correlation analysis, all the wires after clinical use were examined (T1, T2, n = 32). Correlation analysis between the degree of debris and kinetic friction was examined by Spearman’s correlation test, while the correlation between Ra and friction was analysed by Pearson’s correlation test after normality analysis. The alpha level for the statistical tests was established at 5 per cent (P < 0.05).

Results

Scanning electron microscopy

Spearman’s correlation revealed excellent reproducibility (P < 0.0001) for the scores of debris (r = 0.96, at ×18 magnification, and r = 0.99, at ×200).

Analysis of the degree of debris on the T0 wires using SEM showed a complete absence of debris (score 0) for all segments of wire at ×18 and ×200. However, the degree of debris was significantly increased for wires that had remained in the oral environment for 8 weeks (P < 0.05). The median score after clinical use was 2 at ×18 magnification and 3 at ×200 magnification. After cleaning by rubbing with SWS for 1 minute (T2), the levels of debris returned to the T0 values (Figure 3).

Despite significant reduction on the wire, the US method of cleaning seemed to be less effective (P < 0.05) compared with SWS cleaning (Table 1, Figures 3 and 4). SEM examination

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Debris—SEM ×18</th>
<th>Debris—SEM ×200</th>
<th>Roughness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
</tr>
<tr>
<td>Initial</td>
<td>0 (A)</td>
<td>0 (A)</td>
<td>0.03 (A)</td>
</tr>
<tr>
<td>T1–SWS, n = 8</td>
<td>2 (B)</td>
<td>1 (B)</td>
<td>0.25 (B)</td>
</tr>
<tr>
<td>T2–SWS, n = 8</td>
<td>0 (A)</td>
<td>0 (A)</td>
<td>0.25 (A)</td>
</tr>
<tr>
<td>T1–US, n = 8</td>
<td>2.5 (B)</td>
<td>1.25 (B)</td>
<td>1 (B)</td>
</tr>
<tr>
<td>T2–US, n = 8</td>
<td>1 (AB)</td>
<td>0 (AB)</td>
<td>0.25 (AB)</td>
</tr>
</tbody>
</table>

Same letters indicate no statistically significant difference (P > 0.05).
at ×18, with the SWS cleaning method, showed only one wire with a score of 1. All other wires were scored 0. The opposite occurred with the group of US cleaned wires, i.e. seven wires had scores equal to 1. The cleaning was considered to be complete (score = 0) for just one US wire cleaned for 15 minutes when examined at ×18. However, the same wire, when examined at ×200, received a score equal to 1.

Roughness

At T0, the wires showed very low values of Ra, with an average of 0.03 µm and a highly homogeneous behaviour (SD = 0.01). At T1, there was a significant increase in Ra levels ($P < 0.01$). The segments of wire at T1 showed average Ra values of 1.7 µm (SD = 0.77) and 1.2 µm (SD = 0.51), for the pairs of control groups, T1–SWS and T1–US, respectively (Table 1, Figure 5).

After cleaning with a SWS (T2), the average Ra decreased to 0.05 µm (SD = 0.03), returning to values similar to those at T0 (Figure 5). The US cleaned wires at T2 showed an average Ra of 0.3 µm (SD = 0.27). ANOVA showed that both methods of cleaning produced a significant reduction in Ra ($P < 0.01$), providing a Ra similar to that at T0 with no statistically significant difference between the US and SWS methods (Table 1).

Friction

The results revealed no significant difference ($P = 0.55$) between as-received wires and the wires after rubbing (T0–SWS; Table 2). The primary results showed an increase in frictional force from T0 to T1 ($P < 0.05$), with an average increase of 1.02 N for the SWS control sample and 2.19 N for the US control sample (Table 2). A paired analysis (Table 2), comparing T1 (post-clinical) and T2 (after cleaning), showed that there was a significant reduction of the coefficient of friction after wire cleaning with a SWS ($P = 0.035$) and after US cleaning ($P = 0.003$). Therefore, cleaning the wire reduced the values of friction observed after clinical use to levels similar to

![Figure 4](https://example.com/figure4.png)

**Figure 4** Scanning electron microscopy images at ×18 and ×200 of the surface wire after cleaning with the steel wool sponge (T2–SWS) and using ultrasound (T2–US). Note the total removal of debris from the surface of the wire when SWS is used (score 0), while some debris (score = 1) is observed when ultrasound is used.

![Figure 5](https://example.com/figure5.png)

**Figure 5** Roughness mean values for as-received wires (T0), after 8 weeks of clinical use (T1), and after cleaning (T2) with the steel wool sponge (SWS; continuous grey line) or ultrasound (US; dashed line).
At T0, the wires showed very low values of Ra, with an average Ra of 0.3 µm (SD = 0.03) when examined at ×200, received a score equal to 1. However, the same wire, complete (score = 0) for just one US wire cleaned for 15 minutes when examined at ×18. The cleaning was considered to have occurred with the group of US cleaned wires, i.e. seven wires (SWS; continuous grey line) or ultrasound (US; dashed line). These US cleaned wires at T2 showed an average Ra of 0.05 µm (SD = 0.03), returning to values similar to those of as-received wires, despite the cleaning method (T1) and after cleaning (T2) with the steel wool sponge (T2 – SWS) and using ultrasound (T2 – US). Note the total removal of debris from the surface of the wire (Figure 5).

**Discussion**

During orthodontic treatment, friction between the bracket and wire is present from the early stages of alignment and levelling up to the finishing phase. Thus, the resistance to sliding of the bracket along the orthodontic wire is important in clinical practice since a lower friction of orthodontic mechanics can be directly related to a reduction in treatment time (Wichelhaus et al., 2005).

There are few studies on intraoral ageing of orthodontic archwires and its effects on mechanical properties (Eliades and Bourauel, 2005). A recent study (Marques et al., 2010) demonstrated that SS rectangular archwires, when exposed to the intraoral environment for 8 weeks, showed a significant increase in the degree of debris and surface Ra, causing an increase in friction. The present study evaluated the degree of debris, Ra, and friction of orthodontic wires, before and after clinical exposure. In addition, two methods employed to clean orthodontic archwires were assessed. Because of individual variability, this study was designed using pairs of wires, in an attempt to eliminate the influence of the oral hygiene variability. Rectangular SS wires were chosen as these wires are used during mechanical sliding because of their lower coefficient of friction (Drescher et al., 1989; Kapila et al., 1990; Mendes and Rossouw, 1990).

**Correlation between frictional force, the degree of debris, and Ra**

Spearman’s correlation analysis showed a significant correlation between kinetic friction and the degree of debris examined at ×18 (r = 0.55, P = 0.001) and ×200 (r = 0.57, P = 0.0007; Figure 6). Pearson’s correlation analysis revealed a statistically significant correlation between kinetic friction and Ra (r = 0.43, P = 0.0014; Figure 7).

**Table 2** Descriptive statistics [mean, standard deviation (SD), and P value for normality test (Shapiro–Wilk)] and P value (ANOVA and Wilcoxon) for the kinetic frictional force at T0 (as-received), T1 (after 8 weeks clinical used), and T2 (cleaned wires). ANOVA, analysis of variance.

<table>
<thead>
<tr>
<th></th>
<th>Initial T0</th>
<th>T0 – SWS Difference</th>
<th>Steel Wool Sponge (SWS) T1</th>
<th>T2</th>
<th>Difference</th>
<th>Ultrasound (US) T1</th>
<th>T2</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (µN)</td>
<td>7.04</td>
<td>7.18</td>
<td>0.14</td>
<td></td>
<td></td>
<td>9.23</td>
<td>6.97</td>
<td>−2.26</td>
</tr>
<tr>
<td>SD</td>
<td>0.43</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td>0.96</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.32</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>A</td>
<td>A</td>
<td>0.55 (ns)</td>
<td></td>
<td></td>
<td>B</td>
<td>A</td>
<td>0.035*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>A</td>
<td>&lt;0.003**</td>
</tr>
</tbody>
</table>

**Figure 6** Correlation between debris for (a) ×18 (r = 0.55, P = 0.001) and for (b) ×200 magnifications (r = 0.57, P = 0.0007) and the kinetic friction force (N).

**Figure 7** Correlation between roughness (r = 0.43, P = 0.0014) and kinetic frictional force (N).
228 D. NORMANDO ET AL.

It is also important to consider that friction can change during active orthodontic movement as well as the influence of the debris. Although it is difficult to simulate the dynamic relationship between archwire and bracket slots in vitro, this issue should be investigated.

Significant positive correlations were found between the degree of debris on the archwire surface and friction (Figure 6) as well as between Ra and friction (Figure 7). Changes in the structural characteristics of the archwire surface were not examined. It is possible that other factors, in addition to the accumulation of debris on the surface of the archwire, may have contributed to the higher level of friction. Archwire rubbing using a SWS could elevate friction via an increase in surface Ra or could decrease friction by reducing the size of the wire. When comparing the values of friction at T0 to those observed for wires without clinical use and rubbed with a SWS, no significant differences in the levels of frictional force were observed.

Conclusions

SS rectangular wires, when exposed to the oral environment for 8 weeks, showed a significant increase in the degree of debris and surface Ra, causing increased friction levels between the wire and bracket during sliding mechanics. These changes were effectively eliminated after cleaning the orthodontic wire by rubbing with SWS for 1 minute or by immersion in US for 15 minutes, although a SWS seems to be clinically more practical.

References


Drukteinis S, Balcumiene I 2006 A scanning electron microscopic study of debris and smear layer remaining following use of AET instruments and K-flexofil. Stomatologija 8: 70–75


Fernandes N, Leitão J, Jardim L 2005 Influência do tipo de bracket e da angulação de segunda ordem sobre as forças de fricção. Revista Portuguesa de Estomatologia e Cirurgia Maxilofacial 46: 133–143


2003) and lower surface Ra (Kusy and Whitley, 1990). Also, during mechanical incisor retraction, a rectangular SS archwire needs to remain in the oral environment for several months. Edgewise brackets were used in the present study because the slots are flat and can be assembled without any angles or inclinations. The choice of elastic ligatures was made because they are the first option for most clinical orthodontists. Furthermore, it is more difficult to standardize the tying strength when using SS ligatures (Iwasaki et al., 2003).

In the present study, the as-received SS wire showed very low values of Ra, with an average of 0.03 μm. After intraoral exposure for 8 weeks, there was a significant increase in Ra (Table 1). This finding has been previously reported for NiTi (Wichelhaus et al., 2005) and SS (Marques et al., 2010) wires. The degree of debris on the wires showed a similar increase after clinical use. There is little information in the literature regarding the amount of debris on orthodontic wires after clinical use. In this study, using SEM, a debris score of 0 was found for all as-received wires, but after 8 weeks of intraoral exposure, the scores were significantly higher, reaching maximum debris scores.

When the frictional force of SS wires was examined before and after clinical use, the results of this study showed an average increase of 1.02 N (14.5 per cent) for the control SWS samples (T1–SWS) and 2.19 N (31.1 per cent) for the control US sample (T1). Increased friction has previously been found for NiTi wires, with increases ranging from 7 to 137 per cent (Wichelhaus et al., 2005), and for SS wires (Marques et al., 2010), with an increased mean of 20.8 per cent.

No previous study has evaluated the effectiveness of cleaning methods after orthodontic wires have undergone clinical use. Although all the examined variables (quantity of debris, friction and Ra) increased significantly after clinical use for 8 weeks (Tables 1 and 2), the segments of wires showed a significant reduction of these variables when any of the cleaning methods was used. In fact, after cleaning the wire, the variables returned to values similar to those of as-received archwires (Table 2). In addition, the use of SWS was shown to be more efficient for the removal of debris accumulated on the orthodontic wire surface; this method has the advantage that it can be clinically applied in a shorter period of time (1 minute). Shorter times and the use of other material may be equally effective, but this needs to be further investigated.

This test protocol used linear unidirectional sliding mechanics, while orthodontic tooth movement is dynamic. Debris and Ra can potentially increase friction, but these are not the only factors involved in the resistant force system (Burrow, 2009). It is also important to consider that friction can change during active orthodontic movement as well as the influence of the debris. Although it is difficult to simulate the dynamic relationship between archwire and bracket slots in vitro, this issue should be investigated.
Investigated.
archwire and bracket slots
as well as the in
that friction can change during active orthodontic movement
those of as-received archwires (Table 2). In addition, the
cleaning the wire, the variables returned to values similar to
when any of the cleaning methods was used. In fact, after
clinical use for 8 weeks (Tables 1 and 2), the segments of
clinical use. Although all the examined variables (quantity
of debris and surface Ra, causing increased friction levels
for 8 weeks, showed a significant increase of 1.02 N (14.5 percent) for the control
an average increase of 1.02 N (14.5 percent) for the control
made because they are the
results of this study showed
significantly after
The test protocol used linear unidirectional sliding
cult to simulate the dynamic relationship between
orthodontists. Furthermore, it is more dif
cult to standardize
and can be assembled without any
significant positive correlations were found between the
forces and intraoral friction during sliding on a stainless steel archwire.
References
Frank CA, Nikolai RJ 1980 A comparative study of frictional resistances
et al.
Drukteinis S, Balciuniene I 2006 A scanning electron microscopic study of
implications for corrosion potential, nickel release and biocompatibility.
Archwire rubbing using a SWS could elevate friction via an
orthodontic wire by rubbing with SWS for 1 minute or

Kusy R P, Whitley J Q 2000 Resistance to sliding of orthodontic appliances
in the dry and wet states: influence of archwire alloy, interbracket
distance, and bracket engagement. Journal of Biomedical Materials
Research 52: 797–811
Marques I S V, Araújo A M, Gurgel J A, Normando D 2010 Debris,
roughness, and friction of clinical used stainless steel archwires. Angle
Orthodontist 80: 521–527
Seminars in Orthodontics 9: 236–250
Perakaki K, Mellor A C, Qualtrough AJ 2007 Comparison of an ultrasonic
cleaner and washer disinfectant in the cleaning of endodontic files.
Journal of Hospital Infection 67: 355–359
Rossouw P E 2003 Friction: an overview. Seminars in Orthodontics 9:
218–222
Smith D V, Rossouw P E, Watson P 2003 Quantified simulation of canine
retraction: evaluation of frictional resistance. Seminars in Orthodontics
9: 262–280
investigation of the influence of self-ligating brackets, low friction
ligatures, and archwire on frictional resistance. European Journal of
Orthodontics 29: 390–397
Thorstenson GA, Kusy RP 2001 Resistance to sliding of self-ligating
brackets versus conventional stainless steel twin brackets with second-
order angulation in the dry and wet (saliva) states. American Journal of
Orthodontics and Dentofacial Orthopedics 120: 361–370
Thorstenson GA, Kusy RP 2002 Comparison of resistance to sliding
different self-ligating brackets with second-order angulation in
dry and saliva states. American Journal of Orthodontics and Dentofacial
Orthopedics 121: 472–482
Van Eldik DA, Zilm PS, Rogers AH, Marin PD 2004 A SEM evaluation
of debris removal from endodontic files after cleaning and steam
treatment and clinical use on friction in NiTi orthodontic wires. Dental
Materials 21: 938–945
Whitley J Q, Kusy RP 2007 Influence of interbracket distances on the
resistance to sliding of orthodontic appliances. American Journal of
Orthodontics and Dentofacial Orthopedics 132: 360–372

American Journal of Orthodontics and Dentofacial Orthopedics 123:
408–415
Kapila S, Angolkar PV, Duncanson MG, Nanda RS 1990 Evaluation of
friction between edgewise stainless steel brackets and orthodontic wires
of four alloys. American Journal of Orthodontics and Dentofacial
Orthopedics 98: 117–126
Kim TK, Kim KD, Baek SH 2008 Comparison of frictional forces
during the initial leveling stage in various combination of self-ligation
brackets and archwires with custom-designed typodont system.
American Journal of Orthodontics and Dentofacial Orthopedics 133:
15–24
Kuramae M 2006 Evaluation of frictional forces in vitro between brackets
and orthodontic wires in upper cusp distalization according to the
Tweed-Merrifield sequential directional force technique. Thesis,
Dental Faculty of Piracicaba, State University of Campinas, São
Paulo, p. 165
Kusy R P, Whitley J Q 1990 Coefficients of friction for arch wires in
stainless steel and polycrystalline alumina brackets slots. I. The dry
state. American Journal of Orthodontics and Dentofacial Orthopedics
98: 300–312
Kusy R P, Whitley J Q 2000 Resistance to sliding of orthodontic appliances
in the dry and wet states: influence of archwire alloy, interbracket
distance, and bracket engagement. Journal of Biomedical Materials
Research 52: 797–811
Marques IS V, Araújo AM, Gurgel JA, Normando D 2010 Debris,
roughness, and friction of clinical used stainless steel archwires. Angle
Orthodontist 80: 521–527
Mendes K, Rossouw PE 2003 Friction: validation of manufacturer’s claim.
Seminars in Orthodontics 9: 236–250
Perakaki K, Mellor AC, Qualtrough AJ 2007 Comparison of an ultrasonic
cleaner and washer disinfectant in the cleaning of endodontic files.
Journal of Hospital Infection 67: 355–359
Rossouw PE 2003 Friction: an overview. Seminars in Orthodontics 9:
218–222
Smith DV, Rossouw PE, Watson P 2003 Quantified simulation of canine
retraction: evaluation of frictional resistance. Seminars in Orthodontics
9: 262–280
investigation of the influence of self-ligating brackets, low friction
ligatures, and archwire on frictional resistance. European Journal of
Orthodontics 29: 390–397
Thorstenson GA, Kusy RP 2001 Resistance to sliding of self-ligating
brackets versus conventional stainless steel twin brackets with second-
order angulation in the dry and wet (saliva) states. American Journal of
Orthodontics and Dentofacial Orthopedics 120: 361–370
Thorstenson GA, Kusy RP 2002 Comparison of resistance to sliding
different self-ligating brackets with second-order angulation in
dry and saliva states. American Journal of Orthodontics and Dentofacial
Orthopedics 121: 472–482
Van Eldik DA, Zilm PS, Rogers AH, Marin PD 2004 A SEM evaluation
of debris removal from endodontic files after cleaning and steam
treatment and clinical use on friction in NiTi orthodontic wires. Dental
Materials 21: 938–945
Whitley J Q, Kusy RP 2007 Influence of interbracket distances on the
resistance to sliding of orthodontic appliances. American Journal of
Orthodontics and Dentofacial Orthopedics 132: 360–372