Assessment of the dimensions and surface characteristics of orthodontic wires and bracket slots

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Objective: The purpose of this study was to evaluate the dimensions and surface characteristics of orthodontic wires and bracket slots of different commercial brands.

Methods: Thirty metallic brackets (0.022 x 0.028-in and 0.022 x 0.030-in) were divided in three groups: DYN/3M group = Dyna-Lock, 3M/Unitek (stainless steel, or SS); STD/MO group = Slim Morelli (SS); and Ni-Free/MO group = Slim Morelli (Ni-Free). The stainless steel wires (0.019 x 0.025-in) were divided into two groups: MO group = Morelli; and 3M group = 3M/Unitek. The bracket and wire measurements were done by two methods: (a) Surface Electron Microscopy (SEM), and (b) Profile projection. The surface analysis was done qualitatively, based on SEM images and/or by a rugosimeter. The quantitative results were analyzed by ANOVA with Tukey's test ($p < 0.05$) and Student's *t* test.

Results: A significant difference in the dimensions of slots was observed, and the NiFree/MO group showed the greatest changes when compared to the other groups. The analysis of surface topography of the brackets indicated greater homogeneity of the metallic matrix for DYN/3M and STD/MO groups. As for the dimensions of the wires, groups showed statistically different mean heights.

Conclusions: It was concluded that wires and brackets slots can present altered dimensions, which might directly and unintentionally affect the planned tooth movement.

Keywords: Orthodontic brackets. Orthodontic wires. Friction.

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INTRODUCTION

Among the adverse effects of brackets and wires with altered size and geometry, the reduction of dental movements control and increasing friction in the bracket/wire interface stands out.[1,2,26] Undesirable effects such as torque loss of upper and lower incisors (5 – 10°) during space closure mechanics can be attributed to changes in the bracket slot size.[1] The lack of standardization in the wire and bracket slots dimensions will also directly influence on the frictional resistance, hindering the sliding mechanics.[2] It must be observed that with the best combination between bracket and wires, at least 40 g of friction should be included in the force applied to the tooth to start its movement.[3]

Other factors have been linked to the force of friction between brackets and wires during tooth movement; among them, the surface texture of bracket slots and orthodontic wires.[5] Preliminary studies indicate that less homogenous surface characteristics of orthodontic wires are those that have greater surface roughness, which generates more friction in the bracket/wire interface.[5] In addition, orthodontic accessories with less homogenous surfaces tend to be more susceptible to corrosion,[6] which increases the risk of tissue damage, esthetic changes (staining of the tooth by corrosive products) and loss of metal properties.

Companies responsible for the manufacture of orthodontic accessories do not usually indicate their possible size variations; however these variations exist and they are associated to the bracket/wire manufacturing process. Studies point to the need for the introduction of regulatory standards of orthodontic products[24] and therefore technical standards of orthodontic wires and brackets manufacturing were described.[25] Since most orthodontic devices are directly associated with the relationship between size and prescription of brackets and with the section and size of wires, it is important that professionals know more about the materials used in their daily clinical practice. This study aimed to measure the size of rectangular wires and metal bracket slots of different trademarks, *in vitro*. The null hypothesis is the similarity between measures specified by the manufacturers and the actual size of orthodontic brackets and wires. In addition, roughness and surface characteristics of these orthodontic wires and brackets were analyzed.

MATERIAL AND METHODS

a) Analysis of brackets size

Thirty metal edgewise upper right premolar brackets of two different trademarks (3M/Unitek, Monrovia, CA, USA and Dental Morelli, Sorocaba, SP, Brazil) were used. The accessories were divided into three groups of 10 brackets each, as described in Table 1. Two different methods were used to evaluate the slot sizes (height and depth) by one trained operator:

a1) Scanning Electron Microscopy (SEM, Philips XL2000, Holland) – The preparation of brackets consisted of cleaning with acetone by ultrasound (Equipal USC700) for six minutes. After cleaning, the brackets were dried with a nitrogen jet and mounted on metal supports properly identified for SEM observation. After bracket placement, they were pressed against the supports with the aid of a dental probe number 5, so that the bracket bases were parallel to the horizontal plane.

Three frontal images of the brackets were taken: The first was enlarged by 50x, for a general view of the slot conformation (Fig 1); the two others, enlarged by 230x, were taken for a detailed view of each half of the brackets. Thus, for each image at 230x magnification, three measures of the vertical dimension (height) of the slot were analyzed, totaling six measures for each bracket (Fig 1). The average of these values was estimated for each accessory and, finally, for each group.

a2) Profile Projection (PP) – After cleaning the accessories, a profile projector (Nikkon V16, Japan) was used for measuring the vertical and horizontal dimensions of the bracket slots (height and depth). The accessories were fixed to a glass plate using dental wax, so that the slots remained perpendicular to the horizontal plane. The set brackets/glass plate was taken to a projector table, obtaining the shadow projection of the slots. Then, the height and depth of the bracket slot sizes were measured (Fig 2).

Table 1 - Description of studied brackets.

Manufacturer	Bracket	Dimension	Alloy
3M/Unitek	Dyna-Lock; Edgewise Standard (DYN/3M)	0.022 x 0.028-in	Stainless steel (Fe, Ni, Cr)*
Dental Morelli	Slim; Edgewise Standard (STD/MO)	0.022 x 0.030-in	Stainless steel (Fe, Ni, Cr)*
	Slim; Edgewise Standard (Ni-Free/MO)	0.022 x 0.030-in	Stainless steel (nickel free) (chromium, manganese, molybdenum and nitrogen)

* Composition of Stainless Steel Source: Anusavice[7] (1996).

b) Analysis of the wire dimensions

Four rectangular wire segments (0.019 x 0.025-in) of two different commercial brands (3M/Unitek, Monrovia, CA, USA and Dental Morelli, Sorocaba, SP, BR) were used. Each segment was sectioned into six pieces of approximately 1.97 inches each. The samples were divided into two groups according to the wire trademark (Table 2).

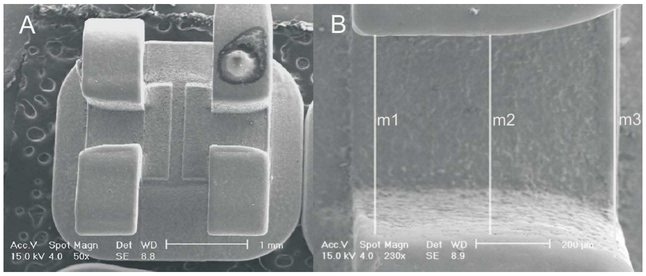

Figure 1 - Scanning Electron Microscopy image of a bracket pertaining to Group III – (A) magnification at 50x and (B) 230x. The lines m1, m2 and m3 are the regions were the measurements were done to calculate slot height. The large variation of bracket dimensions can be observed, especially on mesial and distal ends.

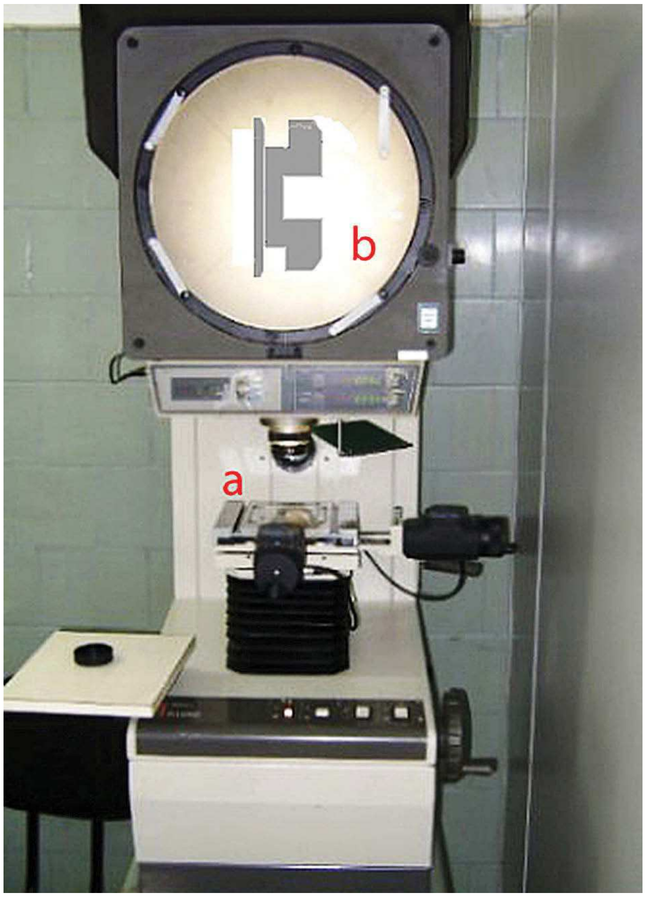

Figure 2 - Profile projector. (a) Once the brackets were correctly positioned on this device, their shadows were projected with a substantial magnification. (b) Bracket height and depth were measured.

The analysis of the wire dimensions was performed using a profile projector (Nikkon V16, Japan). For the measurement of both sections of the wire, the segments were observed in frontal and profile views. After projection of the wire shadows, their height and depth were measured.

c) Surface characteristics analysis of brackets and wires

Bracket and wires surface characteristic analysis was performed by SEM at a magnification of 1000x (Fig 3). Initially, a point above the mesial gingival tie-wing of the bracket slot and a point in the center of the wire segment were pre-determined. The images taken were recorded, identified and randomly distributed in the Microsoft Office Power Point 2010 software,. Subsequently, the images were analyzed by two examiners, using a discrete scale quantitative classification containing four scores: 0 – very rough surface; 1 – rough surface; 2 – smooth surface; and 3 – very smooth surface. Twenty per cent of samples from each group were re-evaluated, in order to verify conformity between examiners.

Table 2 - Description of studied wires.

Manufacturer	Dimension	Alloy
3M/Unitek (3M)	0.019 x 0.025-in	Stainless steel (Fe, Ni, Cr)*
Dental Morelli (MO)	0.019 x 0.025-in	

* Composition of stainless steel. Source: Anusavice[7] (1996).

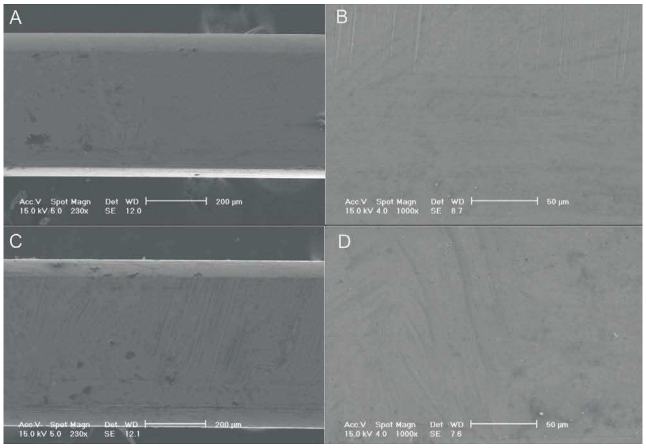

Figure 3 - Scanning Electron Microscopy of wires. (A) 3M-Unitek wires - Group IV –at a magnification of 230x and (B) 1000x; (C) Morelli wires at a magnification of 230x and (D) 1000x.

d) Wire surface roughness analysis

Roughness of wires was evaluated with a surface roughness tester (Mitotoyo SJ201, USA). After cleaning, the wire segments were stuck to a flat table using dental wax, where the roughness tests were carried out. Each wire was rated five times in different regions. Finally, the average values for each wire and different groups were calculated.

All tests were conducted in a climate-controlled environment and with controlled relative air humidity, avoiding any size change of the metal used for manufacturing orthodontic accessories.

e) Statistical analysis

Data normality was confirmed by the Kolmogorov-Smirnov test ($p > 0.05$) and the homogeneity of variances was tested by Levene's test ($p > 0.01$).The results associated with the sizes of the bracket slots were subjected to analysis of variance (ANOVA) followed by Tukey's test ($p > 0.05$). Student's *t* test was used for comparison between heights, depths and surface roughness of wires. The null hypothesis was tested by one-way ANOVA. The analysis of surface characteristics was performed descriptively. Inter-examiners agreement was evaluated by Kappa test and it was considered excellent (Kappa = 0.867). All tests were conducted with the Statistical Package for the Social Sciences, version 17.0 for Windows (SPSS, Chicago, IL, USA).

RESULTS

According to the SEM evaluation (Table 3), DYN/3M, STD/MO and Ni-Free/MO brackets showed slots with heights larger than those specified by the manufacturers ($p < 0.05$). The Ni-Free/MO bracket slots showed larger size, followed by DYN/3M and STD/MO brackets, respectively (Table 3). According to the PP method, there was no statistical difference between the slot heights measured in this study and the standard dimension specified by manufacturer, except for the Ni-Free/MO group (Table 3). On the other hand, regarding the slot depth, DYN/3M and Ni-Free/MO groups showed larger dimensions than those specified by the manufacturers. The comparison between groups did not indicate statistical differences (Table 4).

For the wire dimensions (SEM and PP), the DYN/3M group showed greater heights than that specified by the manufacturers, which was statistically different from the MO groups. With regard to the wire depth, there were no statistical differences (Table 5).

The analysis of surface characteristics of the bracket slots (SEM) showed a better metal polishing for the accessories of the DYN/3M group: 90% of the sample scored 3 and 10% scored 2; followed by the STD/MO group, which showed that 80% scored 1, 10% scored 2, and 10% scored 0. With a more irregular surface characteristic, Ni-Free/MO accessories showed that 40% scored 0 and 60% scored 1.

For the wire segments, the visual surface analysis (SEM) indicated that the MO groups showed 17% scoring 3 and 83% scoring 2. The 3M group showed 33% scoring 3 and 67% scoring 2. The surface roughness of wires indicated no significant differences between groups (Table 6).

DISCUSSION

SEM analysis indicated that the brackets of all groups presented slot height larger than 0.022-in (Table 3). It is important to emphasize that in the Ni-Free/MO group, the presence of changes in the slot conformation was observed, i.e., the height of the slots in the mesial and distal extremities showed greater sizes than those heights in internal extremities (medial), as can be seen in Figure 1.

Table 3 - Statistical analysis of the bracket slot heights (results in inches).

Method	Group	Mean	Median	SD	SE	MIN.	MAX.
MEV	DYN/3M*#	0.02396	0.02371	8.10×10^{-4}	2.8×10^{-4}	0.02251	0.02534
	STD/MO*#	0.02251	0.02252	4.3×10^{-4}	1.3×10^{-4}	0.02199	0.02335
	Ni-Free/MO*#	0.02570	0.02554	9.1×10^{-4}	2.8×10^{-4}	0.02438	0.02697
PP	DYN/3M	0.0223	0.0225	1.0×10^{-3}	3.3×10^{-4}	0.0210	0.0240
	STD/MO	0.02169	0.02185	6.9×10^{-4}	2.2×10^{-4}	0.0200	0.0225
	Ni-Free/MO*	0.02247	0.0223	5.2×10^{-4}	1.6×10^{-4}	0.0220	0.0232

n = 10 brackets (each group);
* = difference between slots dimension obtained (SEM and PP) and the manufacturer specified dimension (One sample t test, $p < 0.05$).
# = Statistical differences between groups (one way ANOVA,followed by Tukey test, $p < 0.05$).

Table 4 - Statistical analysis of bracket slot depth (results in inches).

Method	Group	Mean	Median	SD	SE	MIN.	MAX.
PP	DYN/3M*	0.0308	0.0310	1.3×10^{-3}	4.1×10^{-4}	0.0290	0.0330
	STD/MO	0.02892	0.02935	3.1×10^{-3}	9.9×10^{-4}	0.0250	0.0350
	Ni-Free/MO*	0.0290	0.0290	9.4×10^{-4}	2.9×10^{-4}	0.0280	0.0310

* = difference between bracket dimension obtained (PP) and the manufacturer specified dimension (One sample *t* test, $p < 0.05$).
# = Statistical differences between groups (one way ANOVA, followed by Tukey test, $p < 0.05$).

Table 5 - Height and depth comparison between studied wires (results in inches).

	Manufacturer	Mean	Median	SD	SE	MIN.	MAX.
Wires' height	3M*#	0.01967	0.02200	5.1×10^{-4}	2.1×10^{-4}	0.0190	0.0240
	MO#	0.02072	0.02200	1.8×10^{-3}	7.4×10^{-4}	0.0190	0.0240
	Brand	**Mean**	**Median**	**SD**	**SE**	**MIN.**	**MAX.**
Wires' depth	3M	0.0250	0.0250	6.3×10^{-4}	2.5×10^{-4}	0.0240	0.0260
	MO	0.02457	0.0245	9.4×10^{-4}	3.8×10^{-4}	0.0234	0.0260

* = difference between wire dimension obtained and the manufacturer specified dimension (One Sample *t* test, $p < 0.05$).
# = Statistical differences between Groups (one way ANOVA, followed by Tukey test, $p < 0.05$).

Table 6 -Statistical analysis of wire roughness (results in micrometers).

Manufacturer	Mean	Median	SD	SE	MIN.	MAX.
3M	0.0360	0.0330	1.1×10^{-2}	3.3×10^{-3}	0.0200	0.0640
MO	0.04483	0.0390	1.5×10^{-2}	4.6×10^{-3}	0.0320	0.0880

Thus, the Ni-Free/MO group showed a vertical size of the slots statistically larger than the other groups, followed by the accessories of DYN/3M and STD/MO groups, respectively. Assad-Loss et al[8] also observed rounding of the exterior angle of the brackets slots. Cash et al,[9] when assessing the size and geometry of bracket slots that belonged to 11 different trademarks, concluded that all analyzed accessories showed greater slots than those specified by the manufacturers, confirming the findings of this study.

On the other hand, when the profile projector was used to measure the slot height in this study, no statistical differences were found between the groups. Only accessories from the Ni-Free/MO group showed a significant greater height than that specified by the manufacturers. It should be noted that this method is based on linear measurements from the projection of the shadow of a piece (Fig 2). Therefore, a superimposition of the shadow of the middle region of the slot on the shadow of the lateral region is unavoidable, which can mask the conformation change of the slots observed by SEM from a front view (Fig 1). In this way, it must be considered that the PP methodology does not take into account possible variations in the vertical size of the slots, i.e., the measurement value obtained expresses the smaller vertical size of the bracket slots. This fact makes PP results found for the Ni-Free/MO group more relevant, since accessories of this group showed slot height significantly larger than that specified by the manufacturers (Table 3).

The analysis of the slot depth (PP) did not indicate differences between groups, as the DYN/3M group presented the highest average, followed by the Ni-Free/MO and STD/MO groups respectively. It should be noted that the Ni-Free/MO and DYN/3M groups showed slot depth greater than that specified by the manufacturers. This lack of standardization of size and geometry of bracket slots has been reported by several authors.[3,8,9,26] Kusy and Whitley[2] assessed 24 brackets of different trademarks and found that three brackets had slots that were smaller than specified, while 20 others had slots larger than specified.

Assad-Loss et al[8] studied nine types of brackets of five different trademarks, concluding that there were differences between the slot height and depth when compared with the standard announced by the manufacturer. Onthe other hand, Astrid et al[26] analyzed the sizes of brackets and wires of different trademarks and concluded that the brackets studied showed standardized sizes, while some wires were outside the expected standard.

Regarding the size of the wires, statistical differences between the 3M and MO groups were observed in this study (Table 5). It is interesting to note that the 3M group showed an average height statistically different from that specified by the manufacturers. Regarding the MO group, a wide variety of wire sizes was observed, which indicates a smaller standardization of wires belonging to this group. Professionals must be aware of the possible clinical disadvantages that represent these results. Several authors confirm the direct relationship between the diameter/section of wires and frictional force.[2,10-15] Nanda and Ghosh[2] state that the size and shape of wires and the height and depth of the slots of the brackets are factors that can affect the friction force during sliding mechanics. Kapur, Sinha and Nanda[15] observed that the frictional resistance of stainless steel brackets was higher with increasing diameter/section of the wire.

The qualitative analysis of slot surface characteristics obtained in this study points to the fact that DYN/3M brackets have greater homogeneity of the metal matrix, followed by brackets from STD/MOR and Ni-Free/MOR groups, which confirm previous studies.[17,19] Some authors have reported minor frictional forces during the sliding mechanics on accessories that have slots with smoother surface[18,19] and this fact is an area of controversial discussion.[20] Also, it should be noted that the superficial homogeneity of metal alloy constituent of orthodontic accessories is an important factor in the prevention of the corrosive process, which has become a topic of interest in orthodontic literature.[6]

The qualitative analysis of surface characteristics of wires showed no significant differences between the groups studied (Fig 3), which is a result that was confirmed by the analysis of roughness (Table 6). This consistency between the results obtained by the two different methodologies (SEM and the Roughness Tester) confirms the effectiveness of visual analysis regarding surface characteristics by means of Scanning Electron Microscopy, in accordance with the findings of Menezes et al[17] and Chappard et al.[23]

The standardization of bracket slot sizes seems essential to consolidate certain technological advances, such as the clinical option of using the straight wire technique. Such decision is usually based on angular values that vary according to the chosen prescription and, theoretically, manufacturers should establish such values with precision. This research considers the evident lack of standardization of these accessories during manufacturing process, which may be clinically associated with undesirable changes in tooth positioning and movement. Therefore, it is suggested to conduct studies that investigate this lack of standardization of torque and angulations as specified by the manufacturers for straight-wire brackets with different prescriptions. In addition, it is necessary to understand possible determining factors of this remarkable lack of standardization of orthodontic accessories, such as their constituent alloy and/or their manufacturing processes.

CONCLUSIONS

Based on the results of this study, it can be concluded that:

» There was no standardization in the manufacturing process of orthodontic brackets belonging to the groups DYN/3M, STD/MO and Ni-Free/MO, which showed a significant increase in the average height of their brackets slots;
» Regarding the wire sizes, the DYN/3M group presented a greater height than that specified by the manufacturers, unlike MO group;
» The Ni-Free/MO bracket group showed less homogeneity of the metal matrix, followed by STD/MO and DYN/3M groups, respectively.

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