Influence of facial types on sliding mechanics

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Background/objectives/aims: The present study considered the effect of orthodontic friction in an evaluation of the relationship of craniofacial pattern and surface micro-roughness of fixed appliances as determinants of treatment response and time.
Methods: Brachyfacial (BF; N = 17) and dolichofacial (DF; N = 18) patients treated by canine retraction using sliding mechanics, were identified. One archwire and one bracket per patient (those of the hemi-arch showing the fastest space closure of 4 mm) were subjected to confocal scanning microscopic analysis. Total treatment duration, sliding time, tooth movement rate, topographical surface average roughness (R_a), root mean square roughness (RMS), surface-kurtosis (SK), and surface-skewness (SS) were recorded and compared between groups using the Mann-Whitney U test. Correlations between final micro-roughness and treatment time were investigated using Pearson's coefficient within each craniofacial type ($\alpha = 0.05$). The post-treatment appliance surfaces were examined by SEM.
Results: BF patients recorded a significantly higher sliding time, lowest retraction rates, and greatest final R_a and RMS ($p < 0.001$). A comparison of total treatment time and final SK and SS values yielded no significant differences. Significant positive correlations between sliding time and final R_a were identified in both groups.
Conclusions: Compared with DF subjects, BF patients registered higher friction between the orthodontic components, required longer sliding time, and showed lower retraction rates.
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Introduction

The management of friction generated between the bracket slot and the archwire is of crucial importance for successful orthodontic tooth movement.[1] The reduction of friction and binding may ensure that force delivery to the teeth is low yet continuous, making it biocompatible with the tissues and ultimately decreasing treatment time.[2] In this regard, mechanical and biological parameters are known to modify the generated frictional forces.[3]

From a mechanical perspective, the size of the bracket slot, the inter-bracket distance, the wire dimension, the angulations between the bracket and wire, and the type of material used at the archwire-bracket interface play key roles in determining friction.[4-12]

Influencing biological factors, including plaque and the type of saliva, have been considered to affect appliance friction.[8,13] Moreover, there is a consensus that the craniofacial pattern influences facial muscle strength, mandibular movements, and muscular efforts during mastication.[14] Hyper-divergent craniofacial types have traditionally been associated with weaker musculature.[14,15] Overall, dolichofacial patients are accepted as delivering the poorest masticatory performance, slowest chewing rates, greatest posterior displacement,[13-15] and highest relative effort supplied by the anterior temporalis and the masseter muscles during mastication.[16] Patients with different craniofacial form have also demonstrated substantial differences in the speed of sliding movements during the retraction of anterior teeth when identical mechanics and materials have been used.[2]

Well-controlled clinical studies and more standardised animal experiments are required to provide greater insight into the linked relations between: (1) the craniofacial type (translated into different applied forces) and the final micro-roughness of the sliding surfaces of archwires and brackets; and (2) surface roughness values compared with the duration and speed of tooth movement. Therefore, the present study aimed to evaluate the influence of craniofacial pattern on the final surface micro-roughness of orthodontic fixed appliances and, in turn, on the total and sliding treatment times.

The null hypotheses tested were that: (a) the cranio-facial pattern does not induce changes in the surface micro-roughness of orthodontic fixed appliances (archwires and brackets) during canine sliding, (b) the craniofacial pattern does not induce changes in the total and sliding treatment times, (c) no correlation exists between the final surface micro-roughness of orthodontic fixed appliances and the total and sliding treatment times, and that (d) the rate of space closure does not depend on the craniofacial type.

Materials and methods

Study protocol and sampling procedure

This project was conducted in accordance with the Declaration of Helsinki and Spanish Law 14/2007 for Biomedical Research.[17] The approval of the Ethics Committee of the University of Seville (US, Spain) was obtained after the ethical board of the University completed an independent review of the study protocol. Each subject provided written consent prior to their participation, their anonymity was preserved, and their rights were protected at all times.

Subjects seeking orthodontic treatment were recruited from the Dental Clinic of the University of Seville following a consecutive sampling procedure from December 2012 to February 2015. Individuals were invited to participate in this observational cohort study when they first attended the clinic. The exclusion criteria were subjects who presented with a mesofacial pattern, cognitive impairment, consumption of any drug that could affect bone metabolism, motility disorders, and serious illness.

Brachyfacial and dolichofacial Caucasian males and females aged 12 to 35 years were included in the study to assess the influence of clearly opposite craniofacial types that were out of the standard norm.

An *a priori* power estimation made by an expert statistician from data obtained from a pilot study provided information on the ideal sample size required to achieve statistical significance in the main investigation ($\alpha = 0.05$, $\beta = 0.2$).

Angular and linear measurements were obtained from lateral radiographs of the subjects participating in the main study, which were then used to define the facial types. The measurements included were Mandibular Plane Angle (MPA), Gonial Angle (GA), and Anterior to Posterior total Facial Height ratio (A/PFH).[15] Although hundreds of subjects were screened, the final sample comprised 35 patients, who met the following cephalometric criteria based on Caucasian norms:[15]

- Group 1*:* Brachyfacial patients (BF; N = 17): MPA < 27°, GA < 123.0°, and A/PFH < 62.0 mm.
- Group 2*:* Dolichofacial patients (DF; N = 18): MPA > 37°, GA > 137.0°, and A/PFH > 65.0 mm.

The sample size matched the statistical appraisal, and showed acceptable balance between BF and DF groups. Moreover, homogeneous gender and age distributions were established in both groups to match potential confounding variables.

Orthodontic procedure

A straight wire appliance using a 0.018” slot was placed in all of the subjects. Bilateral sliding mechanics were applied to close first premolar extraction spaces through the individual retraction of the upper left and right canines. Sliding was carried out using elastic power chain traction on an 0.016 × 0.022” stainless steel archwire with metal maxillary canine brackets, prescribed with 0° of torque, 10° of inclination, and 0° of rotation (CEOSA DM, Madrid, Spain). A biweekly re-activation by replacing the elastics was performed in both groups.

The variable of interest was ‘the effect of the bracket and archwire surfaces on sliding mechanics’.

Upon insertion of the stainless steel archwire (just before the activation of the power chains and the extraction of the premolars), a distal mark was made co-incident with the brackets of the right and left canines. Two additional marks were placed 4 mm distally to the first marks on the archwire of both hemi-arches. Only one archwire and one bracket from each subject were selected for analysis and specifically were those from the side which achieved the fastest space closure. The sliding time was recorded from the beginning of tooth movement until each upper canine attained its desired position. Both groups received the same activation frequency and an identical sliding distance of 4 mm was considered to complete space closure prior to the microscopic and clinical assessments. The rate of tooth movement was obtained from the quotient determined by the sliding distance divided by the time taken (in mm/week, as the revisions were performed weekly).

Once canine movement had been completed, the archwires and canine brackets were carefully removed for microscopic analysis. All brackets were retrieved in a standard fashion: (1) the archwires were handled from a region other than that to be analysed; (2) the same debonding plier was used in both groups by detaching the brackets from their bases without interfering with the slots and wings; and (3) all specimens were collected and isolated in plastic tubes.

Confocal laser microscopy analysis

A non-random and non-biased selection was accomplished in both BF and DF groups. Therefore, the orthodontic appliances of the hemi-arch that showed the fastest canine movement were chosen from each patient to maintain consistency. Before being scanned under confocal laser microscopy (TCS SP2, Leica, Germany), the samples (archwires and brackets) were ultrasonically cleaned in 96% ethanol for two minutes, gently air dried, and individually mounted on metal stubs. A reflection image of the surface was obtained using an Argon/Argon, Krypton (Ar/Ar Kr) laser (Emission: 488 nm blue, 543 nm green, 633 nm orange), with the aperture set at 0.3 (×10/0.3 numeric aperture: NA). The recommended scanning resolution was 512 × 512 pixels due to the dimensions and characteristics of the specimens. The stage was displaced 160 μm in the z-direction from the first to the last detectable light reflex, and a z-series of 20 optical sections was generated from each sample to obtain precise and accurate average measurements. In total, 35 archwires and 35 brackets were analysed (one for each patient), so that 700 sections from archwires and 700 sections from brackets were assessed before and after canine sliding.

Surface micro-roughness evaluation

The surface micro-roughness was measured on the optical sections using specific scanning software (LAS-AF-Lite 2.6.0, Leica, Vienna, Austria).

The following roughness parameters were recorded at each of the 10 regions of interest for each selected archwire and bracket: (1) surface average roughness (R_a; μm): the arithmetic average of profile ordinates within the measured section; (2) average root mean square roughness (RMS; μm): the root mean square value of profile ordinates within the measured section; (3) surface kurtosis (SK): the feature of height distribution through the minor peak of the profile; and (4) surface skewness (SS): the measure of the asymmetry of surface deviations about the mean plane to indicate the peaks or pits on a surface. The R_a, RMS, SK, and SS parameters of each sample were assessed before starting the study (initial surface roughness values) and after canine sliding (final surface roughness values) by the same operator on equidistant points per image to reduce bias.

Scanning electron microscopy (SEM) observation

Five archwires and five brackets from each study group were randomly chosen and observed under scanning electron microscopy (JSM-6460LV, Jeol, Tokyo, Japan) with the aim of developing a qualitative complementary analysis that may illustrate the objective-quantitative data recorded. Therefore, 30% of the specimens from each group were examined under SEM by focusing on specific areas at different magnifications (from ×50 to ×500). The SEM provided a three-dimensional (3D) (x/y/z) resolution of 4 nm at an accelerating voltage of 20 kV and a working distance (WD on the z-axis) of 39 mm. Precise scanning software (INCA Energy, Oxford, UK) was used to examine the morphology of the tested surfaces.

Statistical analysis

Descriptive statistics including means and standard deviations (SD) were calculated for each variable, orthodontic appliance, and craniofacial pattern. The intra-examiner reliability was investigated by using the Kappa test.

Given that males and females have different muscle tones, a chi-squared test was applied to compare the gender distributions in both groups. The same statistical probe was applied to compare the distributions of Angle dental and skeletal classes between BF and DF subjects.

Because the Kolmogorov-Smirnov test did not assume a normal distribution of the outcome variables, the Mann-Whitney U test was applied to compare the total treatment durations, sliding times, rates of tooth movement (or space closure), and final surface roughness values between the groups.

The Pearson coefficient was calculated to evaluate the correlation between the final surface micro-roughness and the total and sliding treatment times depending on the craniofacial type.

All data analyses were made with the SPSS/PC+ v. 17.0 statistical package software (SPSS, Inc., IL, US), setting the cut-off level for the statistical significance at $\alpha = 0.05$.

Results

The relevant statistical results are displayed in Tables I–III. The Kappa statistic showed perfect intra-examiner reliability ($k = 1$) for all of the assessments performed. The study sample (N = 35) comprised 17 BF and 18 DF patients, with a mean age of 24.64 ± 8.29 and 20.27 ± 7.1 years, respectively. A balanced gender distribution was confirmed in both groups ($p = 0.615$). Most participants had an Angle Class II relationship regardless of their craniofacial type ($p = 0.903$). The dental and skeletal classes coincided in all cases. The maxillary first premolars of all patients were extracted as part of orthodontic treatment (Table I).

Time evaluation

The mean and standard deviation (SD) values of total treatment time and canine sliding time for each group are detailed in Table I. The average total treatment time for the entire sample was 28.55 ± 3.09 months, with no significant between-group differences ($p = 0.935$). The average sliding time was 21.48 ± 4.88 weeks. The duration of the distal canine movement produced significant differences depending on the craniofacial pattern and was shown to be higher in BF patients ($p = 0.0001$) (Table I).

Retraction rate evaluation

Since the sliding distance was constant in all cases (4 mm), the speed of space closure was defined as the inverse of sliding time. DF patients recorded the highest rates of tooth movement (retraction rates) ($p = 0.0001$). Table I presents the rate values of each study group.

Surface micro-roughness evaluation

The initial surface roughness was similar between the fixed appliances (Table II). These measures were taken to exclude any defective materials (derived from fabrication or standardisation) which could have led to a misinterpretation of the final surface roughness values.

Significantly lower R_a values were detected in the DF group for the archwires and brackets after 4 mm of sliding mechanics ($p < 0.001$). The RMS values recorded in the BF group for the archwires and brackets were significantly higher than those of the DF group ($p < 0.001$). Neither the SK nor the SS values resulted in significant differences between BF and DF subjects ($p < 0.05$) (Table II).

Association between micro-roughness and treatment time

The Pearson coefficient showed a significant correlation between the time taken to move the canines by sliding mechanics and the final R_a values of the orthodontic fixed appliances in both groups ($p < 0.001$ for BF patients, and $p < 0.05$ for their DF counterparts). The greater the final surface micro-roughness (registered in BF patients), the longer the time for canine movement. However, no significant correlation between the final R_a values and the total treatment time was observed in any group (Table III).

SEM analysis

Representative SEM images of the tested groups after sliding are provided in Figures 1 and 2. The archwires utilised in BF patients showed a rougher surface topography (Figure 1A). Conversely, the appliances in the DF group exhibited relatively flat surfaces with micropores (Figure 1B).

The bracket slot surfaces were assessed at the same site, which was confined to a squared area outlined

Table I. Clinical parameters of the study patients.

Clinical parameters (Mean ± SD)	Craniofacial type: Brachyfacial (N = 17)	Craniofacial type: Dolichofacial (N = 18)	*p* value
Mean age [y][1]	24.64 ± 8.29	20.27 ± 7.1	0.231
Total treatment time [m][2]	28.59 ± 3.76	28.51 ± 2.4	0.935
Sliding time [w][3]	**25.35 ± 3.70 ↔	**17.83 ± 2.35	0.0001
Rate of tooth movement [mm/w]	0.17 ± 0.002	0.23 ± 0.03	0.0001
Gender [N (%)]			0.615
Female	9 (52.9%)	9 (50%)	
Male	8 (47.1%)	9 (50%)	
Angle classification [N (%)]			0.903
Class I	6 (35.3%)	6 (33.3%)	
Class II	11 (64.7%)	12 (66.7%)	
Class III	-	-	
Pretreatment [N (%)]			
Extraction	17 (100%)	18 (100%)	-
No extraction	-	-	

[1][y]: years. [2][m]: months. [3][w]: weeks.
Test used: Man-Whitney U test; *: $p < 0.05$; **: $p < 0.001$.

Table II. Surface roughness values of the orthodontic fixed appliances after canine sliding depending on the craniofacial type of the patients.

Samples analysed Archwires [N = 17 (G1) + 18 (G2) = 35] Brackets [N = 17 (G1) + 18 (G2) = 35]		Craniofacial type Mean ± SD: G1: Brachyfacial (BF; N = 17)	Craniofacial type Mean ± SD: G2: Dolichofacial (DF; N = 18)
R_a[1]	Archwires	**360.75 ± 137.698 ↔	**219.10 ± 78.344
	Brackets	**655.16 ± 119.8 ↔	**273.24 ± 35.79
RMS[2]	Archwires	**315.52 ± 156.33 ↔	**231.95 ± 121.82
	Brackets	**665.39 ± 237.22 ↔	**275.44 ± 109.78
SK[3]	Archwires	-0.837 ± 1.063	2.136 ± 1.038
	Brackets	0.448 ± 1.063	-1.259 ± 1.038
SS[4]	Archwires	0.443 ± 0.55	1.619 ± 0.53
	Brackets	-0.31 ± 0.55	-0.43 ± 0.536

[1]R_a: surface average roughness. [2]RMS: root mean square roughness. [3]SK: surface kurtosis. [4]SS: surface skewness. SD: standard deviation.
Test used: Mann-Whitney U test; *: $p < 0.05$; **: $p < 0.001$.

Table III. Correlations among surface roughness values and treatment times depending on the craniofacial type of the patients.

	Craniofacial type: Brachyfacial (N = 17)			Craniofacial type: Dolichofacial (N = 18)		
	TT[4]	FR[1]	IR[2]	TT[4]	FR[1]	IR[2]
FR[1]	0.496			-0.398		
IR[2]	-0.021	0.503*		0.153	0.523*	
ST[3]	0.567*	0.688**	0.168	-0.206	0.472*	-0.153

[1]FR: final surface microroughness. [2]IR: initial surface microroughness. [3]ST: sliding time. [4]TT: total treatment time.
Test used: Pearson correlation coefficient; *: $p < 0.05$; **: $p < 0.001$.

in red (Figure 2A) before setting the final microscope magnification. A jagged surface containing edge-shaped micro-irregularities was observed in the BF group (Figure 2B). The brackets of DF patients showed the smoothest surfaces, with a few, scattered porosities (Figure 2C).

Discussion

The present study evaluated the influence of BF and DF types on the surface micro-roughness of orthodontic fixed appliances after canine sliding and, consequently, on the total and sliding treatment times. The first and fourth null hypotheses were rejected because (a) the craniofacial pattern significantly affected the final surface micro-roughness of the archwires and brackets (assessed by R_a and RMS values); and (d) the rate of space closure depended on the craniofacial type. The second and third null hypotheses were partially rejected since (b) the craniofacial pattern was related to changes in canine sliding time but not in total treatment time; and (c) significant correlations between sliding time and final surface micro-roughness of the orthodontic appliances were identified between BF and DF patients. The total treatment time, however, yielded no significant correlations with the final surface roughness of archwires and brackets in any group (Tables I–III).

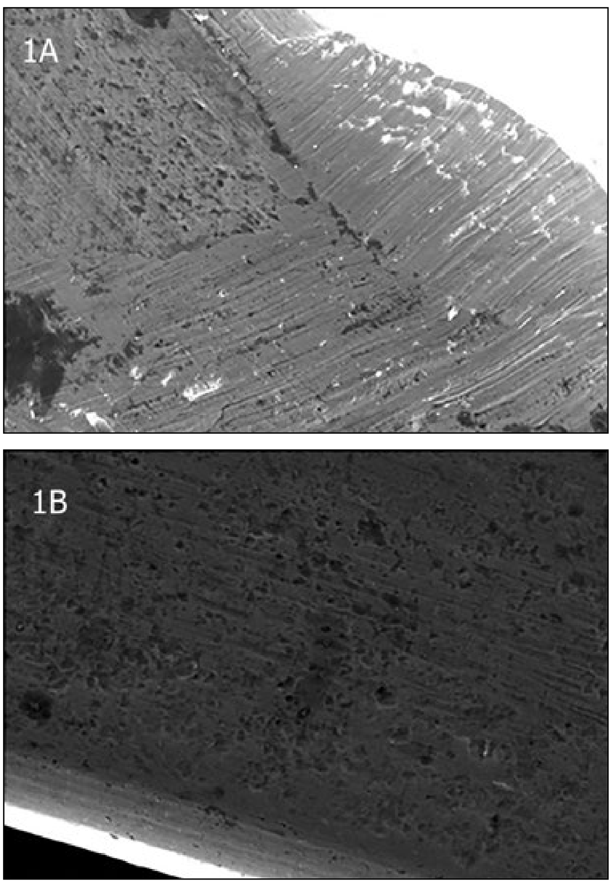

Figure 1. Representative topographic SEM images of archwires' surfaces after canine sliding.
1A. Stainless steel archwire of a BF patient (×50 μm).
1B. Stainless steel archwire of a DF patient (×50 μm).

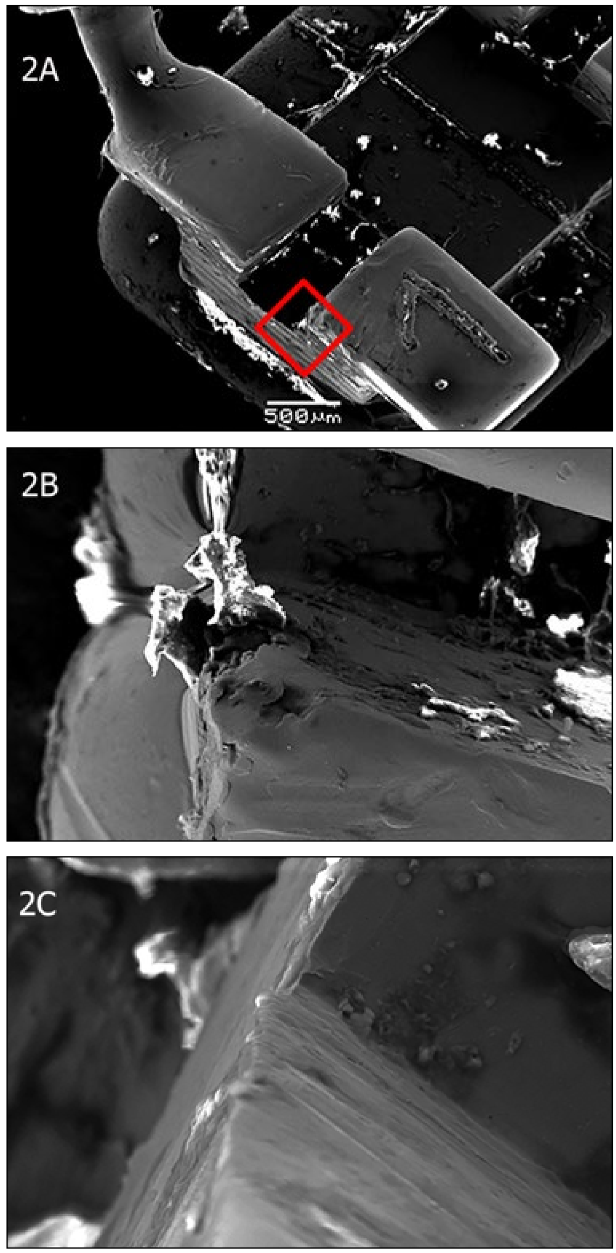

Figure 2. Representative topographic SEM micrographs of brackets' surfaces after canine sliding.
2A. External view of a bracket after being removed from a maxillary canine. The evaluation was performed in the square area outlined in red (×500 μm). The same position was examined in all samples.
2B. Distal wing of the upper left canine bracket of a BF subject (×50 μm).
2C. Mesial wing of the upper right canine bracket of a DF patient (×50 μm).

R_a, which is the most frequently used parameter for machined materials,[18] measures the average of the peaks and valleys from the arithmetic mean elevation of the surface. RMS roughness is the square root of the sum of the squares of the individual heights and depths from the mean line. These parameters are primarily concerned with the relative departure of the contour in the vertical direction and do not provide information regarding the slopes, sizes and shapes of the asperities or the frequency and regularity of their occurrence. Nevertheless, R_a and RMS are recommended for classifying surfaces of the same type that are produced by an identical manufacturing method.[19] Because the present investigation analysed the surface micro-roughness of archwires and brackets, such measures were the most meaningful. After canine sliding, BF patients recorded significantly higher R_a and RMS values than DF subjects in both types of orthodontic fixed appliances (Table II). These significant results may be related to the different facial muscular patterns and therefore varying masticatory forces, which could affect the occlusal forces delivered onto the surfaces of archwires and brackets.[20,21] Such premature degradation of the opposite sliding surfaces may enhance the frictional forces contributing to the notching and binding effects identified in those subjects with more powerful musculature.[22,23]

In the current investigation, both confocal laser microscopy and SEM analyses were performed. SEM is the most utilised and recommended method for studying morphological changes at the archwire-bracket interface.[7,24-26] The representative SEM observations (despite being only a qualitative assessment with intrinsic limitations), pointed to a possible correlation between roughness pattern and craniofacial type in line with the objective results obtained by confocal analysis (Table III; Figures 1 and 2). After sliding mechanics, the archwires and brackets in DF patients showed slightly scratched but flat surfaces, containing slot-like micropores and microgrooves (Figures 1B and 2C), while BF patients registered the roughest surfaces in both types of appliances (Figures 1A and 2B).

In contrast, SK and SS are dimensionless statistical height descriptors frequently used to help with characterising the surfaces, and yielded no significant differences after canine sliding (Table II). However, the brackets from BF patients tended to reach higher SK values (also showing more peaks on their surfaces). Contrary results were obtained following archwire examination, which warrant further investigation. Moreover, the brackets of both groups exhibited comparably negative SS values, suggesting the presence of numerous valleys, pits, and/or holes. The positive values recorded for the archwires (mainly in DF subjects, with even higher values) indicate a generally smooth surface with occasional but relatively large 'hills'[18,19] (Table II; Figures 1 and 2).

Given that greater surface damage is likely over time,[11] the duration of space closure over a fixed distance was measured in the current study. The lack of standardisation of the distances would confound the results, since the time of frictional contact could affect the level of roughness.[22,23]

Significant correlations were identified between the time taken to move the canines and the final R_a values of the archwires and brackets. The retraction of the canines was significantly faster in the DF group (Table I). This may have been mediated by muscle and chewing forces. However, the difference did not translate into shorter total treatment times (Tables I and III). This may also relate to additional time requirements for DF patients to complete other tasks, such as vertical control[27] or finishing and detailing. Nevertheless, the overall rates of tooth movement in the current experiment were lower than those stated in the literature.[28,29] Further research is necessary to determine whether NiTi springs, among other methods, are faster than the current power chain for supplying sliding mechanics.[28-30]

Apart from the power estimation calculated from the data obtained in the pilot study, the limited sample size is partly justified by the inclusion of two different groups with acceptably homogeneous characteristics related to type measurements, and also in gender and age distribution. Another limitation was the inclusion of only BF and DF subjects for comparing opposite facial types. The inclusion of a control sample of mesofacial patients would have allowed a comparison of the present results with those of ideal subjects with well-balanced cranio-facial features.[13-16,31] As previously documented,[32-35] ethnic background, gender, and age may affect the strength of the masticatory muscles and the forces exerted by the archwires, which may in turn influence the surface micro-roughness after orthodontic movement. With few exceptions, males and/or young people have been identified as having superior muscle power to females and/or the elderly.[33-35] Hence, in addition to the balanced gender and age distribution, it would have been valuable to enrol patients from other ethnicities to allow an extrapolation of the results. Although the present research was limited to Caucasians in an attempt to achieve a homogeneous sample (since the facial types were classified according to the standardised Caucasian norms),[15] future studies should be extended to broader settings. Finally, further confounding limitations may relate to possible operator variations while debonding the brackets and removing the appliances (regardless of using a cautious protocol to avoid damage or contact with the area of evaluation), the precision and resolution of the laser microscopy, the subjective nature of the SEM interpretations, and other occasional human errors in controlling the distance of space closure to be the same in all patients.

It is concluded that the craniofacial type (excluding the mesofacial, which was not the focus of the investigation) appears to relate to the surface micro-roughness of orthodontic fixed appliances as measured by the R_a and RMS parameters after canine movement, and can also affect sliding time and the rate of space closure. BF patients registered higher friction values between the orthodontic appliance components and therefore required greater sliding time, identified by lower rates of tooth movement. However, the present study requires confirmation by larger samples with different clinical and socio-demographic profiles.

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