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The effects of lubrication on the static frictional resistance of orthodontic brackets

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Background: Difficulties are experienced with the collection and storage of freshly harvested human saliva to use as a lubricant for the laboratory testing of the frictional resistance of orthodontic brackets. In order to overcome these difficulties, researchers have suggested the use of saliva substitutes due to their ease of storage and consistency of properties throughout testing. Others have criticized the use of artificial saliva and prefer the dry state. The present study aimed to compare the effects of human saliva and an artificial saliva (Saliva Orthana®) with the dry state for the static frictional resistance testing of orthodontic brackets.
Methods: The static frictional resistance and the lubrication effect of human saliva, Saliva Orthana® and the dry state were investigated using upper central incisor stainless steel brackets and 0.019 x 0.025 inch stainless steel wires in an Instron® Universal Testing Machine. Static frictional resistance was measured 100 times for each lubrication state. The 'wettability' of each lubricant was determined by measuring the contact angle against a stainless steel surface using the CAM 200 Optical Contact Angle Meter. Distilled water acted as a control. The viscosity of each lubricant and their Newtonian or non-Newtonian fluid behaviour under stress was measured using a Brookfield Digital Rheometer Model DV-III+.
Results: The differences in static frictional resistance between the three lubricants when examined as a group did not reach statistical significance (p = 0.059). The difference between human saliva and Saliva Orthana® was considered to be of weak statistical significance and clinical relevance (Means: 0.917 N; 0.819 N: p = 0.053). Human saliva and the dry state revealed very similar mean frictional values (Means: 0.917 N; 0.875 N: p = 0.932). The contact angle tests indicated a statistically significant difference between the lubricants with Saliva Orthana® having the smallest angle and therefore the highest 'wettability'. Human saliva had the highest initial viscosity and behaved as a non-Newtonian fluid, contrasting with Saliva Orthana® and distilled water, both of which behaved as Newtonian fluids.
Conclusion: The current results indicate that artificial saliva is not an ideal alternative to human saliva for friction testing in the laboratory. The results therefore support the proposal that, when human saliva is not available, it may be preferable to test orthodontic frictional resistance in the dry state.
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Introduction

Pre-adjusted edgewise appliances utilise sliding mechanics as brackets are moved relative to an archwire. Friction is created within any sliding system and evidence suggests that at least 50 per cent of an applied force may be lost in overcoming frictional resistance.[1] Factors that have been implicated in influencing friction include archwire composition and dimensions,[2-5] bracket width and material,[5-10] ligatures and method of ligation[2,11-15] and lubrication.[8, 9,16,17]

A lubricant can reduce friction between materials but the applied fluid must have wettability properties.[17] A challenge in the laboratory testing of friction is the reproduction of an in vivo environment that mirrors the clinical situation as closely as possible. In addition, human saliva can be difficult to collect and store.[18] It has been proposed that artificial saliva be used to test friction due to its ease of storage and consistency of properties throughout testing[19,22] while others have criticised its use.[20,21] Previous studies which have investigated the friction values obtained when testing in dry and wet conditions have shown conflicting results, with either an increase in friction in the wet state,[8] a reduction in friction[18] or no effect.[16] Studies using human saliva as a lubricant have produced unpredictable results as saliva can demonstrate inconsistent behaviour, sometimes acting to reduce friction and at other times showing adhesive behaviour and therefore increasing the friction values.[19] Despite this, the results from laboratory comparisons of the coefficients of friction measured with human saliva, water and artificial saliva have led to the suggestion that, for the wet state, only human saliva should be used to assess the coefficients of friction generated with sliding.[20] The validity of the experimental use of artificial saliva as a substitute for human saliva has also been questioned.[21]

The aims of this study were therefore:

1. To compare the effect of different lubrication states (dry state, human saliva and Saliva Orthana®) on the static frictional resistance of orthodontic brackets.

2. To assess comparative wettability of the lubricants by comparing the contact angles of human saliva and Saliva Orthana® to stainless steel using distilled water as a control.

3. To compare the viscosity of human saliva and Saliva Orthana® using distilled water as a control.

The Null Hypotheses to be tested were:

1. There is no significant difference in the static frictional resistances of stainless steel brackets and archwires measured in the laboratory in the dry state or when lubricated with human saliva or Saliva Orthana® artificial saliva.

2. There is no significant difference in contact angles between human saliva, Saliva Orthana® and distilled water.

Material and methods

Measurement of static frictional resistance

Equilibrium® 2, maxillary left central incisor stainless steel brackets (Dentaurum, Ispringen, Germany) were used. These incorporated seventeen degrees of torque and four degrees of tip, and had slot dimensions of 0.022 x 0.030 inch. The archwires used were 14 inch straight lengths of 0.019 x 0.025 inch rectangular stainless steel (Dentaurum, Ispringen, Germany). Ortholastic™ elastomeric ligatures (Dentaurum, Ispringen, Germany) tied the archwire to the brackets for all tests. All brackets, archwires and ligatures carried the same batch code to ensure manufacturer's consistency. Freshly harvested unstimulated human saliva and artificial saliva (Saliva Orthana®, Nycomed, Birmingham, UK) were the lubricants tested and were compared with the dry state.

A sample size calculation was carried out based on data from a previous pilot study which used the same experimental protocol.[22] This had shown a mean static frictional resistance with human saliva of 0.860 N (SD: 0.213) and a mean static frictional resistance with Saliva Orthana® of 0.857 N (SD: 0.178). At an α–level of 0.05, a sample size of 100 in each group would have 94 per cent power to detect a clinically relevant difference in means of 10 per cent.

The samples to be tested were prepared the day before. The wires were cut to 4 inch lengths and the brackets and wires were de-greased with acetone before being allowed to air dry. The brackets, archwires and elastomeric ligatures to be tested with human saliva or Saliva Orthana®, were soaked in the pre-determined lubricant for 24 hours to ensure surface adsorption of the constituent glycoproteins.[22] Samples to be tested were randomised to avoid the effect of ambient change on the system and a new bracket, wire and ligature were used for each test.

A custom-made jig was utilized to mount the bracket at a zero degree angulation and eliminate bracket/archwire binding effects. A fixed pointer extended from the side of the bracket mount and was used to adjust the bracket slot angulation as determined by a protractor attached to the jig. The wire was pre-tensioned within the jig to eliminate any curvature and ligated against the bracket with a conventional elastomeric ligature. Comprehensive details of the jig have been described in previous publications.[23,24]

Prior to testing, the lubricant was applied to the bracket, archwire and ligature with a soft brush to ensure full coverage and lubrication of the system. The ends of the jig were held by the Instron® Universal Load Testing Machine (Model Number 4505, Instron®, High Wycombe, UK) which provided a tensile force and enabled the archwire to slide through the bracket slot with a steady crosshead speed of 0.5 mm/min, running over 1 millimetre. The results were displayed as a force/displacement curve on a computer connected to the Instron® machine. The initial peak was recorded as the force required to overcome static frictional resistance and initiate movement.

Measurement of the contact angles

The contact angle is a measurement of the 'wettability' of a liquid to a solid surface and the smaller the contact angle, the greater the 'wettability'. The CAM 200 Optical Contact Angle Meter (KSV Instruments Ltd., Helsinki, Finland) is a fully computer-controlled instrument based on the video capture of images and automatic image analysis to measure static or dynamic contact angles. It was used to measure the contact angles of human saliva and Saliva Orthana® against 3 x 7 mm stainless steel blanks of unprocessed bracket profile (Dentaurum Inc., Ispringen, Germany). The contact angle of distilled water was measured as a known Newtonian fluid control.

A manual glass syringe with a fine needle was held vertically in an adjustable holder and loaded with a pre-determined lubricant. Screwing the dispenser slowly, extruded a droplet of lubricant. When the droplet touched the metal surface, a video captured image was obtained. From this image, software measured the angle between the metal surface and a tangent to the droplet on its right and left sides (Figure 1). This test was performed five times for each lubricant and each test produced five means. The mean of the five measurements was subsequently calculated for each fluid.

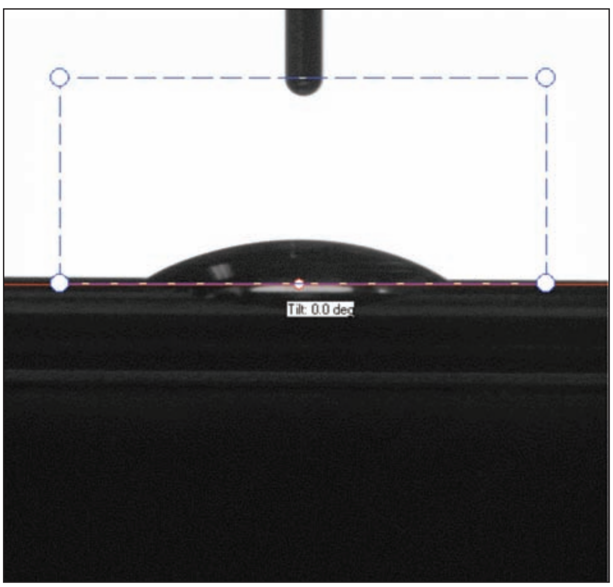

Figure 1. Measurement of the contact angle.

Measurement of the viscosity

To relate the viscosity of the lubricants to the frictional resistance results, the viscosity of human saliva and Saliva Orthana® was measured using a Brookfield Digital Rheometer DV-III+ (Brookfield Engineering Laboratories Inc., Middleboro, MA, USA). Distilled water was used as a Newtonian fluid control. A Newtonian fluid is one in which viscosity does not change with the rate of shear stress. Water is a thin fluid with low viscosity that is independent of flow rate.[25] Non-Newtonian behaviour is found when the dynamic viscosity of a liquid changes as the rate of shear changes. Colloids are examples of non-Newtonian fluids.[25]

A spindle immersed in the test fluid through a calibrated spring was driven by the Rheometer. The shear rate was increased gradually from 13.2 sec^{-1} to 330 sec^{-1}. The apparatus was computer controlled and the viscosity was measured in milliPascals (centipoise) and shear rate measured in units of reciprocal seconds (1/sec). The software was pre-programmed to make 25 readings per test over a 10 second interval. Each test was repeated five times per lubricant and the data were collected and saved in Microsoft Excel®. A graph was obtained showing the relationship of viscosity to shear rate (Figure 2).

Under the guidance of the statistical author (DRM), analysis of the data was carried out using SPSS 14.0 (Statistics Package for Social Sciences, Chicago, IL, USA). A one-way Analysis of Variance (ANOVA) was used to test the global effects of lubricants on static frictional resistance, and the data were further examined using *t*-tests with a Bonferroni correction to compare each pair of lubricants. The Kruskal-Wallis test was used to analyse the contact angles of three independent groups of lubricants in which the data were unsuited for parametric analysis. The Mann-Whitney U-test to was used to post-hoc analyse the contact angle results for statistical differences between each pair of lubricants.

Contact angle and viscosity measurements were also carried out as post-hoc tests to the main frictional resistance experiments. All investigations were undertaken in the laboratory of the Department of Biomaterials, UCL Eastman Dental Institute, London.

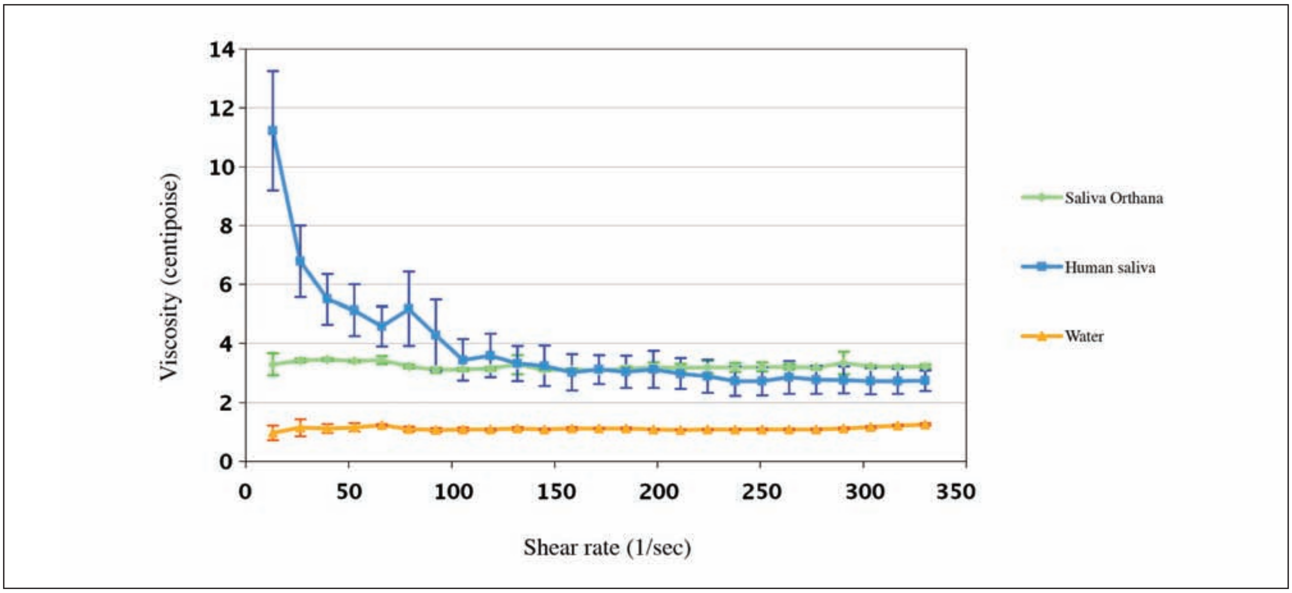

Figure 2. Viscosities of human saliva, Saliva Orthana® and distilled water.

Results

Static frictional resistance

The data gathered from static frictional testing were entered into SPSS and examined visually for a normal distribution using a 'box-and-whisker' plot. This method indicated that the data followed a normal distribution and therefore parametric tests were carried out to analyse for statistical differences between the groups. The data were reported to a precision of three decimal places.

Table I indicates the mean static frictional resistance, 95 per cent confidence interval (CI), standard deviation (SD) and standard error (SE) for each lubrication state. The mean static frictional resistance reduced from saliva to the dry state followed by Saliva Orthana®. The 95 per cent confidence interval was seen to minimally increase, with Saliva Orthana® having the lowest and human saliva the highest.

Table II shows the one-way ANOVA results testing for global differences between independent groups of lubrication states. The p value was 0.059, which was greater than the assigned significance level of $p \leq 0.05$ but approached borderline significance. Further analysis of the data in Table III showed a pair-wise comparison of mean change in static frictional resistance by the different lubrication modes. These were post-hoc tests performed subsequent to the one-way ANOVA to identify pairs of groups that approached borderline significance. All p values were adjusted by the Bonferroni correction to minimise type-I errors that can result from multiple comparisons.[26] The greatest difference in observed means was shown to be between the human saliva and Saliva Orthana® groups (mean difference -0.098 N, 95%CI -0.197 to 0.001, $p = 0.053$). There was a trend toward higher frictional resistance in the human saliva group that approached a level of statistical significance as indicated by the borderline p value and the 95 per cent confidence interval barely crossing zero. The difference between the dry state and the Saliva Orthana® groups was not statistically significant (mean difference 0.056 N, 95%CI -0.043 to 0.156, $p = 0.527$). The dry and human saliva groups had similar mean static frictional resistances (mean difference 0.042 N, 95%CI -0.058 to 0.142, $p = 0.932$).

Contact angles

A 'box-and-whisker' plot indicated that the contact angle data did not follow a normal distribution and therefore, non-parametric tests were performed. Table IV shows the median and inter-quartile range of the contact angle for each lubricant. There was a trend of reducing median contact angle with water as the highest and Saliva Orthana® the lowest. The results

Table I. Descriptive statistics – static frictional resistance.

	Dry state	Human saliva	Saliva Orthana®
Number tested	100	100	100
Mean frictional resistance (N)	0.875	0.917	0.819
95% CI	0.816, 0.934	0.859, 0.976	0.763, 0.876
Standard Deviation	0.294	0.295	0.284
Standard Error	0.030	0.030	0.028

Table II. One-way Analysis of Variance (ANOVA).

Source of variation	Sum of squares	DF	Mean squares	F-ratio	*p*
Between groups	0.485	2	0.242	2.864	0.059
Within groups	24.973	295	0.085		
Total	25.458	297			

Table III. Multiple comparisons.

(I) Type of lubrication used	(J) Type of lubrication used	Mean Difference (I-J) N	Std. Error	*p* †	95% CI	
					Lower	Upper
Dry	Saliva Orthana®	0.056	0.041	0.527	-0.043	0.156
Saliva	Dry	0.042	0.041	0.932	-0.058	0.142
Saliva Orthana®	Saliva	-0.098	0.041	0.053	-0.197	0.001

†Adjustment for multiple comparisons (Bonferroni correction)

Table IV. Descriptive statistics – contact angle.

Lubricant	Number tested	Median (degrees)	Inter-quartile range
Water	25	67.423	1.958
Human saliva	25	40.268	10.684
Saliva Orthana®	25	24.664	10.839

Table V. Kruskal-Wallis test – contact angle.

Lubricant	Number tested	Mean rank	Chi-Square	DF	*p*
Water	25	63.00			
Human saliva	25	34.84	58.525	2	< 0.001
Saliva Orthana®	25	16.16			

Table VI. Mann-Whitney U-test – contact angle.

	Lubricants 1		Lubricants 2		Lubricants 3	
	Water	Human saliva	Water	Saliva Orthana®	Human saliva	Saliva Orthana®
Mean rank	38.00	13.00	38.00	13.00	34.84	16.16
Sum of ranks	950.00	325.00	950.00	325.00	871.00	404.00
Mann-Whitney U	0.000		0.000		79.000	
2-tailed *p*	< 0.001		< 0.001		< 0.001	

of the Kruskal-Wallis test in Table V suggested a statistically significant difference in contact angles globally between the three lubricants ($p < 0.001$).

The Mann-Whitney U-test (Table VI) demonstrated a significant difference ($p < 0.001$) between each of the pair-wise groups: water and human saliva, water and Saliva Orthana®, human saliva and Saliva Orthana®. The highest and lowest contact angles were created by water and Saliva Orthana® respectively while human saliva lay in between.

Viscosity

The results of viscosity tests are shown in Figure 2. Saliva Orthana® and distilled water showed median viscosities of 3.204 and 1.100 Centipoise respectively and were unaffected by shear rate, suggesting Newtonian fluid behaviour. In contrast with Saliva Orthana® and distilled water, the viscosity of human saliva had an inverse relationship to shear rate between 13.2 sec^{-1} and 150 sec^{-1}, implying non-Newtonian fluid behaviour. Human saliva viscosity values began at 11.218 Centipoise and decreased as the shear rate increased to values comparable with Saliva Orthana®.

Discussion

This study standardised the majority of variables including bracket material, slot dimensions, archwire material, archwire dimensions, slot-archwire angulation, and ligation to enable the effect of the lubricants to be isolated and compared. The results of the friction test showed no statistically significant difference between human saliva, Saliva Orthana® and the dry state. This supports the findings of a previous study using the same lubrication states.[22] However, since the p-value approached borderline significance ($p = 0.059$), it was decided to conduct post-hoc tests to evaluate any between-group differences. The results showed a difference in means between human saliva and Saliva Orthana® that was of weak statistical significance ($p = 0.053$) with the latter tending towards a lower mean frictional resistance. This borderline result makes meaningful recommendations difficult. The study was adequately powered (94 per cent) to detect a clinically relevant difference in means. The result was 'borderline' from the perspective of clinically relevant difference (11 per cent) and also close to the 5 per cent level of statistical significance.

Other tests for mean differences were far more conclusive and indicated that there was clearly no statistically significant difference between the dry state and Saliva Orthana® ($p = 0.527$). Human saliva and the dry state showed the closest mean values ($p = 0.932$) and were almost identical in magnitude reflecting a p-value close to unity. Considered in their entirety, the results lend support to previous suggestions that the dry state may be a better alternative to the use of human saliva for laboratory friction testing compared with the use of artificial saliva.[20, 21]

Contact angle measurements provided further clues to the lubrication behaviour during friction tests whereby Saliva Orthana® demonstrated significantly lower friction values than human saliva ($p = 0.053$). This suggested that Saliva Orthana® was acting as a more efficient lubricant due to its higher 'wettability'.

The results suggest that previous studies in which these lubricants have been used can be considered valid. However, when human saliva is not available during laboratory-based friction testing, the dry state may be a better alternative rather than the use of a saliva substitute. The dry state facilitates a quicker and more convenient procedure compared with the lubricated state. Testing friction in the dry state may be potentially advantageous due to the convenient preparation of samples and the avoidance of collection and storage of human saliva. In addition, human saliva may vary in consistency and this may affect testing repeatability. Consistent results in the dry state are a potential benefit, provided that other factors are monitored and controlled.

Conclusions

Differences in static frictional resistance demonstrated that using human saliva, artificial saliva and the dry state approached statistical significance ($p = 0.059$). The static frictional resistance achieved when lubricating with human saliva compared closely to that with the dry state ($p = 0.932$). Human saliva and Saliva Orthana® showed different viscosity behaviour under sliding stress, with human saliva producing non-Newtonian fluid behaviour. This may have led to a weak statistically significant difference in frictional resistance between the two lubricants ($p = 0.053$).

Although previous studies, which have used a saliva substitute as a lubricant during laboratory-based friction testing, may be considered valid, it is recommended that, for future studies, the dry state may be a better alternative.

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