European Journal of Orthodontics 26 (2004) 579–583
European Journal of Orthodontics vol. 26 no. 6
© European Orthodontic Society 2004; all rights reserved.

Factors affecting friction in the pre-adjusted appliance

M. M. Moore, E. Harrington and W. P. Rock
School of Dentistry, University of Birmingham, UK

SUMMARY A jig was constructed to measure the frictional forces created by various tip and torque values in association with two types of straightwire bracket moving along stainless steel (SS) archwires. Forces were measured during translation of the bracket using an Instron machine. Steel and cobalt chromium brackets were tested in association with 0.019×0.025 and 0.021×0.025 inch steel archwires at tips from 0 to 3 degrees and torque values in 2 degree increments from 0 to 6 degrees.

The mean values for static (2.2 N) and kinetic (2.1 N) friction were very similar ($P = 0.71$), as were the overall friction values for stainless steel (2.1 N) and chromium cobalt (2.2 N) brackets of similar dimensions ($P = 0.44$). Use of 0.021×0.025 inch wire produced three times as much friction as 0.019×0.025 inch wire, 3.0 N against 1.2 N ($P < 0.01$). Increased tip and torque were associated with highly significant increases in friction ($P < 0.01$). Every degree of tip produced approximately twice as much friction as comparable torque. The main conclusion of the study was that space closure should be completed on a 0.019×0.025 inch archwire before a 0.021×0.025 inch wire is used to complete tooth alignment.

Introduction

The Straight-Wire® appliance was the first orthodontic mechanism to be based upon sliding mechanics. The advantages of this system in controlling the positions and angulations of teeth throughout treatment are such that different variants of the technique are now the most popular appliances in use. The translation technique provides good rotational control, although associated friction may delay tooth movement and increase anchorage requirements (Frank and Nikolai, 1980; Drescher *et al.*, 1989). Consequently, it is essential to have an understanding of the frictional forces between brackets and wires in order to produce effective tooth movement within the range of optimal biological response (Ogata *et al.*, 1996).

The physical laws of friction were derived from straight-line sliding of materials in the dry state. Orthodontic tooth movement combines the laws of friction and physiology. The dynamic environment of the mouth repeatedly breaks and resets the friction lock between the bracket and archwire to produce tooth movement as a series of short steps rather than as smooth continuous motion. In an attempt to reproduce this type of movement in the laboratory, some authors have mounted brackets to allow freedom of movement against the archwire (Kapila *et al.*, 1990; Bednar *et al.*, 1991), although the relevance of such studies to the clinical situation is uncertain (Tselepis *et al.*, 1994). Usually experiments concerning orthodontic friction have used a rigid apparatus, designed either to slide a bracket along a fixed wire or to draw a wire through a static bracket slot.

There are two main types of friction. Static friction is the smallest force needed to start the motion of solid surfaces that were previously at rest, whereas kinetic friction is the force that resists the sliding motion of one solid object over another (Omana *et al.*, 1992a). The classical description of friction depicts the maximal value of static frictional force as the product of the coefficient of static friction and the resultant normal force at right angles to the archwire.

Light continuous forces move teeth most efficiently and with the least amount of patient discomfort and tissue damage (Rygh, 1986). However, root surface area, bone density and occlusal interferences each influence the effect of force on a tooth, while friction between the bracket and archwire adds yet another variable (Peterson *et al.*, 1982; Quinn and Yoshikawa, 1985).

It has been estimated that 50 per cent of applied orthodontic force is dissipated due to friction, so that the total force applied to orthodontic brackets has to be twice that needed to produce an effective force in the absence of friction (Proffit and Fields, 1993). However, excessive force is counter-productive due to increased bracket friction and the potential loss of posterior anchorage (Omana *et al.*, 1992b).

Factors which might affect friction in a pre-adjusted appliance include the wire size and archwire stiffness, which in turn depends not only on cross-sectional size and Young's modulus, but also on inter-bracket distances (Frank and Nikolai, 1980; Vaughan *et al.*, 1995). Stainless steel (SS) wire has been found to be smoother than nickel titanium (Kusy *et al.*, 1998).

The effect of bracket width upon friction was investigated by Tidy (1989) who found that frictional force was inversely proportional to bracket width and that wide SS brackets sliding on SS wires produced less friction than other combinations of alloys. Other studies have shown that wire friction decreases as bracket width increases (Proffit and Fields, 1993); although some have reported increased friction with wide brackets (Kapila *et al.*, 1990). New bracket designs, in particular self-ligating types, have been produced in an attempt to reduce friction (Kapur *et al.*, 1998).

Of all the contributory factors, bracket slot to wire angulation has been said to be the main determinant of frictional resistance to tooth movement (Frank and Nikolai, 1980).

The aim of the present study was, therefore, to measure the effects of different angles of tip and torque on the static and kinetic friction produced when a SS and a cobalt chromium bracket, respectively, were translated along 0.019 × 0.025 and 0.021 × 0.025 inch SS archwires.

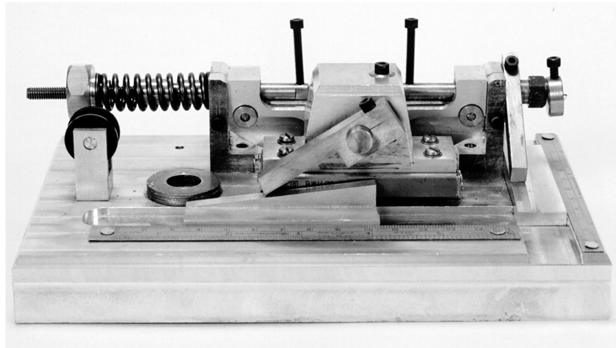

Figure 2 The rear view of the test apparatus, showing the wedge used to adjust for tip and the slide. The jig was bolted to the Instron through the hole to the right of the pulley.

Materials and method

Cast SS brackets (Advant-edge, TP Orthodontics, Morley, Leeds, UK) were tested along with cast cobalt chromium brackets (Nu-edge LN brackets, TP Orthodontics). The two brackets were selected from the range available to be of similar size. This was confirmed with the aid of a calibrated optical microscope accurate to 4 μm. The slot of the Advant-edge bracket measured 560 × 763 μm × 3.4 mm and the Nu-edge dimensions were 559 × 711 μm × 3.6 mm.

The archwires used were 0.019 × 0.025 and 0.021 × 0.025 inch SS wires (Resilient Rectangular Wire, 3M Unitek, Monrovia, California, USA). The dimensions of the wires were checked using a micrometer and found to be accurate to three decimal places. Translation of upper left canine brackets relative to an archwire was achieved using a specially made friction testing apparatus (Figures 1 and 2) bolted to the lower crosshead of an Instron 5544 tension testing machine (Instron UK, High Wycombe, Bucks, UK).

A bracket under test was cemented into a recess in the end of a brass rod, inserted through an aluminium block which was screwed to a SS slide (no. 238-3486, RS Components, Corby, Northants, UK). This virtually friction-free slide was pulled horizontally by a nylon line passed under a pulley and attached to the upper jaw of the Instron machine. The archwire was slipped into rigid SS end tubes of minimally larger internal diameter and spot welded in place to leave a 14 mm length of unsupported wire, which is commensurate with the unsupported span in the mouth following loss of one premolar. The end tubes passed through the centres of brass rods, which formed part of the apparatus and could be locked by means of grub screws to maintain alignment.

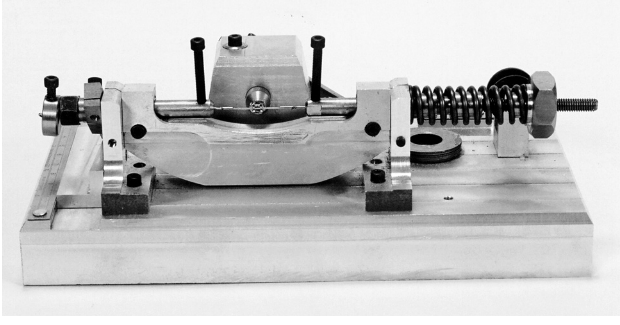

Figure 1 The frontal view of the test apparatus. The tension adjusting spring is on the right.

A bracket was positioned correctly on the rod by first ligating it to a full-size 0.021 × 0.025 inch SS wire which acted as a jig on the apparatus. The brass mounting rod was then advanced towards the bracket, which was cemented into its recessed end using light-cured Transbond adhesive (3M Unitek). Use of a full-size archwire in association with the composite layer effectively removed the prescription from the bracket. The mounting wire was then replaced by a test wire that had been cleaned in alcohol, and the bracket was attached to it using an elastic module (plastic ligature, American Orthodontics, Sheboygan, Wisconsin, USA). The archwire was then tensioned to 50 g by means of the coil spring at one end (Figure 1). During tensioning, twisting of the archwire was prevented by means of grub screws, which locked the brass rods and end tubes. The screws were maintained vertically throughout to produce a bracket and archwire mounted in a passive state. In order to confirm that this was so, a preliminary friction test was carried out by moving the unligated bracket along the archwire. Little measurable friction was recorded.

One Advant-edge and one Nu-edge bracket were used for all tests to avoid the introduction of inconsistencies caused by variations in mounting positions had a number of different brackets been used. Careful examination of the brackets after testing, using a stereoscopic microscope at ×40 magnification, revealed no gross signs of wear or deformation that might have affected the results.

It was possible to adjust the relationship of the bracket to the archwire in two planes. Tip was set by means of the tip adjusting arm on the bracket mounting rod, which acted on a calibrated inclined plane (Figure 2). Torque was adjusted using a similarly calibrated adjusting arm, which altered the angulation of the G-clamp carrying the archwire. Tip and torque were introduced separately and were never tested in combination. Each bracket/archwire/tip or torque combination was tested 10 times, a new ligature being fitted before each set of 10 tests.

Static and kinetic friction forces were measured throughout 8 mm translations of the bracket along the archwire at a crosshead speed of 20 mm/minute. Tip was varied from 1 to 3 degrees and torque was introduced in 2 degree increments from 2 to 6 degrees. These values were chosen to produce a balanced data set after preliminary tests had shown total friction lock at tip values greater than 3 degrees with the 0.021 × 0.025 inch wire. There were 480 individual tests. Specimens were dry tested at ambient room temperature (24°C). Static friction (the peak force required to initiate movement) and kinetic friction (the mean force required to maintain movement) were recorded digitally. Kinetic force was measured from the trace after 4 mm of translation, i.e. halfway across the total movement.

Statistics

Preliminary investigations suggested that the overall mean friction forces would be around 2 N with a standard deviation of 0.17N. A relevant between-group difference of 100g produces a standardised difference of 0.6 and suggests a sample size of 160 to give 90 per cent power at the 0.01 significance level (Altman, 1991). The results were analysed using the general linear model (GLM) ANOVA program in Minitab 13 (Minitab Inc., State College, Pennsylvania, USA) with force as the dependent variable and bracket, friction type, wire size, tip and torque as factors in the model. *Post-hoc* Tukey tests were used where these were relevant. One-way ANOVA was used to produce group means.

Results

Raw data for the two brackets are shown in Table 1. GLM analysis revealed significant effects for each of the main variables in the full equation (Table 2).

Separate analyses of the effect of each factor using one-way ANOVA are shown in Table 3. The mean values for starting (static) and sliding (kinetic) friction

Table 1 Friction values for different wire sizes and different tip and torque settings.

		Advant-edge bracket					Nu-edge bracket				
Friction type	Wire size	Tip (°)	Torque (°)	Mean	SD	Range	Tip (°)	Torque (°)	Mean	SD	Range
Static	0.019 × 0.025	1	0	0.34	0.08	0.25–0.50	1	0	0.37	0.24	0.19–0.78
Static	0.019 × 0.025	2	0	0.69	0.10	0.50–0.78	2	0	0.67	0.37	0.22–1.52
Static	0.019 × 0.025	3	0	2.01	0.16	1.74–2.28	3	0	1.82	0.70	0.54–3.03
Kinetic	0.019 × 0.025	1	0	0.41	0.07	0.29–0.53	1	0	0.74	0.10	0.61–0.9
Kinetic	0.019 × 0.025	2	0	0.29	0.06	0.20–0.36	2	0	0.82	0.24	0.47–1.18
Kinetic	0.019 × 0.025	3	0	1.42	0.09	1.32–1.60	3	0	2.06	0.34	1.52–2.61
Static	0.021 × 0.025	1	0	1.73	0.19	1.47–2.00	1	0	1.61	0.28	1.17–2.03
Static	0.021 × 0.025	2	0	3.09	0.13	2.90–3.32	2	0	4.45	0.28	3.78–4.83
Static	0.021 × 0.025	3	0	4.58	0.24	4.19–4.89	3	0	7.47	0.66	6.92–8.9
Kinetic	0.021 × 0.025	1	0	1.81	0.09	1.70–1.94	1	0	1.82	0.56	1.72–1.93
Kinetic	0.021 × 0.025	2	0	3.15	0.17	2.95–3.55	2	0	4.38	0.17	3.99–4.56
Kinetic	0.021 × 0.025	3	0	4.52	0.36	4.0–5.12	3	0	8.27	0.52	7.34–8.96
Static	0.019 × 0.025	0	2	1.26	0.05	1.17–1.32	0	2	1.84	0.11	1.75–2.01
Static	0.019 × 0.025	0	4	1.39	0.02	1.35–1.42	0	4	1.65	0.05	1.59–1.76
Static	0.019 × 0.025	0	6	1.54	0.07	1.42–1.62	0	6	1.67	0.07	1.51–1.75
Kinetic	0.019 × 0.025	0	2	1.31	0.03	1.26–1.34	0	2	1.67	0.03	1.59–1.7
Kinetic	0.019 × 0.025	0	4	1.39	0.01	1.38–1.41	0	4	1.66	0.07	1.64–1.69
Kinetic	0.019 × 0.025	0	6	1.44	0.05	1.34–1.49	0	6	1.46	0.04	1.38–1.52
Static	0.021 × 0.025	0	2	1.31	0.09	1.22–1.52	0	2	0.98	0.04	0.95–1.05
Static	0.021 × 0.025	0	4	2.92	0.23	2.58–3.31	0	4	1.01	0.08	0.94–1.17
Static	0.021 × 0.025	0	6	5.48	0.11	5.27–5.69	0	6	2.35	0.10	2.25–2.59
Kinetic	0.021 × 0.025	0	2	1.03	0.03	0.99–1.10	0	2	1.08	0.02	1.06–1.12
Kinetic	0.021 × 0.025	0	4	2.45	0.24	2.07–2.79	0	4	1.23	0.04	1.19–1.31
Kinetic	0.021 × 0.025	0	6	4.51	0.31	3.92–4.79	0	6	1.89	0.03	1.86–1.95

SD, standard deviation.

Table 2 Multiple analysis of variance using the general linear model program.

Variable	Sum of squares	df	*F* value	Significance
Bracket	1.823	1	36.516	0.001
Friction type	0.418	1	8.368	0.004
Wire size	389.160	1	7795.653	0.001
Tip	346.650	2	3472.048	0.001
Torque	63.149	2	632.502	0.001

Table 3 One-way ANOVA for the effects of each main variable considered separately.

	n	Mean friction (N)	SD	*F* value	Significance
Friction type					
Static	240	2.2	1.7	0.14	0.709
Kinetic	240	2.1	1.7		
Bracket					
Advant-edge	240	2.1	1.4	0.61	0.435
Nu-edge	240	2.2	2.0		
Wire size					
0.019 × 0.025	240	1.2	0.6	178.61	0.001
0.021 × 0.025	240	3.0	2.0		
Tip (°)					
0	240	1.8	1.1	58.96	0.001
1	80	1.1	0.7		
2	80	2.2	1.7		
3	80	4.0	2.6		
Torque (°)					
0	240	2.4	2.2	12.45	0.001
2	80	1.3	0.3		
4	80	1.7	0.6		
6	80	2.5	1.5		

SD, standard deviation.

were very similar at 2.2 and 2.1 N, respectively, $P = 0.71$. The overall mean values for the friction associated with the stainless steel (2.1 N) and chromium cobalt brackets (2.2 N) were also almost identical.

The mean value for combined static and kinetic friction readings with the 0.021 × 0.025 inch wire was 3.0 N, almost three times that for the 0.019 × 0.025 inch wire, $P = 0.001$.

As mentioned earlier, 3 degrees of tip was the maximum that could be tested in association with a 0.021 × 0.025 inch archwire. In order to provide a balanced data set for the purposes of analysis, it was necessary to have three levels of torque. Torque was therefore introduced in 2 degree increments to permit testing at 2, 4 and 6 degrees. Combined friction rose from 1.3 N at 2 degrees to 2.5 N at 6 degrees, a significant increase, $P = 0.001$.

Post-hoc Tukey comparisons for tip and torque showed that the subsets were all homogeneous, confirming the validity of the ANOVA result.

Discussion

This paper describes the preliminary friction results obtained using a jig designed and constructed to study frictional forces at the archwire/bracket interface. On the whole the mechanism worked well, although it was rather cumbersome to adjust the tip and torque values using the inclined planes.

Preliminary tests showed that the friction values were remarkably constant over a set of 10 tests and that it was not necessary to change the elastic module between each individual test. This is supported by the low standard deviations in Table 1. The range of tip and torque was limited by the fact that 3 degrees of tip was the maximum that could be introduced in association with a 0.021 × 0.025 inch archwire without producing so much binding that the bracket was immovable.

The friction traces varied in character. Sometimes there was an initial peak as static friction was overcome, after which the trace fell back somewhat. On other occasions the trace rose after the initial movement, indicating that kinetic friction was higher than static friction. The overall effect of such variable traces was that the mean values for static and kinetic friction were similar ($P = 0.71$); they were, therefore, combined for the analysis of the effects of bracket type, wire size, tip and torque.

The fact that two brackets of similar size but different alloys produced almost identical friction when moved along SS archwires supports Kusy and Whitley (1990).

Wire size had a highly significant effect upon friction in that the 0.021 × 0.025 inch wire produced three times as much friction as the 0.019 × 0.025 inch wire. The effect was particularly noticeable at 3 degrees of tip, when 8.27 N was recorded for movement of the Nu-edge bracket along the 0.021 × 0.025 inch wire. Molar tubes were not included in the study, but it is clear that attempts to close residual space in the buccal segment by mesial movement of a premolar and the adjacent molar could generate very substantial frictional forces if tip was not first removed from the brackets. A 0.019 × 0.025 inch wire appears to offer a more appropriate combination of lower friction and acceptable tip control during space closure.

Although there was no overall frictional difference between the two brackets, it is clear that the Nu-edge bracket produced more friction than the Advant-edge when used on a 0.021 × 0.025 inch arch at tips of 2 and 3 degrees. This suggests that either the shape or the metallurgy of the chrome cobalt bracket made it more susceptible to binding.

The mean frictional forces with 0.021 × 0.025 inch wire were almost three times those with 0.019 × 0.025 inch wire (Table 3). This suggests that the largest wire should be used for a final tooth alignment arch, but only when space closure has been completed.

The apparently anomalous mean friction values at zero tip and torque are due to the inclusion of the high torque results in the zero tip tests and *vice versa*.

The main conclusion from this study is that modest amounts of bracket tip produce rapidly increasing friction, probably due to the effects of binding between the bracket and the archwire. An increase in bracket tip from 1 to 3 degrees almost quadrupled friction (Table 3); further testing was not possible with 0.021 × 0.025 inch wire at greater than 3 degrees of tip due to complete friction lock. This supports the view of Frank and Nikolai (1980), that bracket slot to wire angulation is the most important determinant of friction in orthodontics.

Torque had a less dramatic effect on frictional forces. From the results for both wires in Table 3 it can be seen that 6 degrees of torque produced a mean frictional force of only 2.5 N against the 4.0 N mean with 3 degrees of tip. This is not surprising as there would be 10 degrees of slop in the torque plane when using a 0.019 × 0.025 inch wire in a 0.022 inch bracket slot and approximately 4 degrees of slop in association with the 0.021 × 0.025 inch wire.

The present study tested the influence of tip and torque separately. A second apparatus is under construction that will permit the simultaneous introduction of differing amounts of tip and torque.

Conclusions

1. Movement of brackets along a 0.021 × 0.025 inch SS wire produced almost three times as much friction as movement along a 0.019 × 0.025 inch wire, the overall means being 3.0 and 1.2 N, respectively.
2. Friction doubled with every degree of bracket tip.
3. Twisting the wire in the torque plane generally produced proportionately less friction than tip.
4. Friction was similar overall for SS and chromium cobalt brackets of similar dimensions.
5. Space closure should be completed on a 0.019 × 0.025 inch archwire before a 0.021 × 0.025 inch wire is used to complete tooth alignment by utilizing the full prescription of the brackets.

Address for correspondence

W. P. Rock
School of Dentistry
St Chad's Queensway
Birmingham B4 6NN
UK

References

Altman D G 1991 Practical statistics for medical research. Chapman and Hall, London, p. 456

Bednar J R, Gruendeman G W, Sandrik J L 1991 A comparative study of frictional forces between orthodontic brackets and arch wires. American Journal of Orthodontics and Dentofacial Orthopedics 100: 513–522

Drescher D, Bourauel C, Schumacher H-A 1989 Frictional forces between bracket and arch wire. American Journal of Orthodontics and Dentofacial Orthopedics 96: 397–404

Frank C A, Nikolai R J 1980 A comparative study of frictional resistances between orthodontic bracket and arch wire. American Journal of Orthodontics 78: 593–609

Kapila S, Angolkar P V, Duncanson Jr M G, Nanda R S 1990 Evaluation of friction between edgewise stainless steel brackets and orthodontic wire for four alloys. American Journal of Orthodontics and Dentofacial Orthopedics 98: 117–126

Kapur R, Sinha P K, Nanda R S 1998 Frictional resistance of the Damon SL bracket. Journal of Clinical Orthodontics 32: 485–489

Kusy R P, Whitley J Q 1990 Coefficients of friction for archwires in stainless steel and polycrystalline alumina bracket slots. 1. The dry state. American Journal of Orthodontics and Dentofacial Orthopedics 98: 300–312

Kusy R P, Whitley J Q, Ambrose A A, Newman J G 1998 Evaluation of titanium brackets for orthodontic treatment: part I. The passive configuration. American Journal of Orthodontics and Dentofacial Orthopedics 114: 558–572

Ogata R H, Nanda R S, Duncanson Jr M G, Sinha P K, Currier G F 1996 Frictional resistances in stainless steel bracket–wire combinations with effects of vertical deflections. American Journal of Orthodontics and Dentofacial Orthopedics 109: 535–542

Omana H, Moore R, Bagby M D 1992a Frictional properties of metal and ceramic brackets. Journal of Clinical Orthodontics 26: 425–432

Omana H, Moore R, Bagby M D, Erickson L 1992b Frictional properties of ceramic brackets during simulated cuspid retraction. Journal of Dental Research 71: 168 (abstract)

Peterson L, Spenser R, Andreasen G 1982 A comparison of friction resistance for nitinol and stainless steel wire in edgewise brackets. Quintessence International 13: 563–571

Proffit W R, Fields H W 1993 Contemporary orthodontics, 2nd edn. Mosby Year Book, St Louis

Quinn R S, Yoshikawa D K 1985 A reassessment of force magnitude in orthodontics. American Journal of Orthodontics 88: 252–260

Rygh P 1986 Periodontal response to tooth-moving force: is trauma necessary in orthodontics? In: Graber L W (ed.) State of the art, essence of the science. C V Mosby, St Louis, pp. 100–115

Tidy D C 1989 Frictional forces in fixed appliances. American Journal of Orthodontics and Dentofacial Orthopedics 96: 249–254

Tselepis M, Brockhurst P, West V C 1994 Frictional resistance between brackets and arch wires. American Journal of Orthodontics and Dentofacial Orthopedics 106: 131–138

Vaughan J L, Duncanson Jr M G, Nanda R S, Currier G F 1995 Relative kinetic frictional forces between sintered stainless steel brackets and orthodontic wires. American Journal of Orthodontics and Dentofacial Orthopedics 107: 20–27

Copyright of European Journal of Orthodontics is the property of Oxford University Press / UK and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.