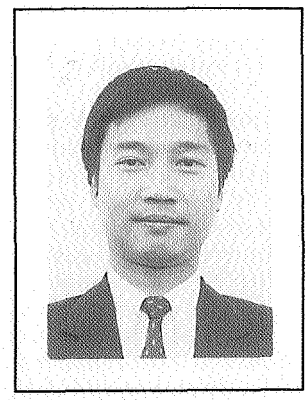
sciendo DOI: 10.2478/aoj-1991-0017

© October 1991 Australian Orthodontic Journal, Melbourne, Australia



Friction resistance between edgewise brackets and archwires

Kuat Shiun Ho B.D.S.(Sheffield), M.D.Sc.(Melb)*
Victor C. West M.D.Sc.(Melb), B.Sc(Melb)+
Melbourne, Australia

ABSTRACT: This study quantified the dynamic frictional force encountered when TMA, Orthonol and multistranded stainless steel archwires were pulled a distance of 2mm through ceramic and stainless steel brackets. The current literature is inadequate and incomplete, for example, no data was found on rectangular multistranded archwires. The following factors were investigated: archwire material, archwire size, archwire-to-bracket angulation, bracket material, archwire and bracket slot surface roughness and lubrication in the form of artificial saliva. A total of 156 different combinations were investigated. A universal testing machine was used to pull the ligated archwires through the brackets, and record the friction. A four way analysis of variance with one nesting (archwire size) was carried out on 1,560 measurements to assess the results. All factors and interactions tested were significant in determining friction. Friction was found to increase with: archwire angulation and archwire size (exceptions were seen in some TMA archwires). Friction decreased with lubrication. There was a definite relationship between friction and archwire and bracket material. There was no definite relationship between archwire surface roughness and friction. Highest friction was observed with ceramic bracket and TMA archwire. The range of friction was 1.02 to 9.95 Newtons. The magnitude of the friction recorded is substantially larger than the forces applied in orthodontic movement clinically. It is proposed that the values recorded should be utilised as a means of comparing the effects of different factors, rather than for the quantification of friction in vivo.

Reference: Aust.Orthod.J.12(2):95-99

MeSH words: orthodontic wires
Key words: multistranded wires, nickel-titanium, beta-titanium wires, friction

INTRODUCTION

Friction is defined as the force exerted by either of two contacting bodies tending to oppose the relative tangential displacement of the other. There are two forms of friction: (1) kinetic (dynamic) friction which occurs during motion, and (2) static friction which prevents motion.

In fixed orthodontic therapy, teeth can be moved by either utilizing retraction archwire where minimal friction is involved, or sliding mechanics where friction is a major consideration. Friction is a factor in all forms of sliding mechanics such as retraction of teeth into extraction sites, levelling and alignment where the archwire must slide through the bracket slots and tubes. Ricketts et al. (1986) stated that 'reduction of mechanical influences of friction and binding as teeth are being moved, would facilitate the application of lighter and more effective forces, which would produce less strain on the supporting anchorage'.

The problem of friction in sliding mechanics has been mentioned in many papers (Stoner 1960, Gottlieb et al. 1972, Thurow 1972, Schudy 1975, Creekmore 1976, Andreasen and Zwanziger 1980, Kapila and Sachdeva 1989). Specific studies of friction in sliding mechanics, where orthodontic archwires are drawn through brackets, have been published in seventeen papers to date (Nicholls 1968, Anderson and Maris 1969, Andreasen and Quevedo 1970, Kamiyana and Sasaki 1973, Echols 1975, Riley, Garret and Moon 1979, Frank and Nikolai 1980, Peterson, Spencer and Andreasen 1982, Garner, Allai and Moore 1986, Stannard, Gau and Hanna 1986, Baker Nieberg, Wiemer and Hanna 1987, Kusy and Whitley 1988, Drescher and Bourauel 1989, Kusy and Whitley 1989, Popli, Prateen, Germane and Gunsolley 1989, Rock and Wilson 1989, Tidy 1989).

Various techniques have been used to measure friction, including a dynamometer (Nicolls 1968), a weight basket (Frank and Nikolai 1980), a force gauge (Andreasen and Quevedo 1970, Petersen, Spencer and Andreasen 1982), and a universal testing machine (Riley 1979, Garner et al. 1986, Stannard et al. 1986, Tselepis 1989).

A review of the literature indicated the multifactorial nature of friction. There is general agreement that in sliding mechanics, friction increases with angulation of archwire-to-bracket (Nicholls 1968, Andreasen and Quevedo 1970, Frank and Nikolai 1980, Peterson et al. 1982), size of archwire (Andreasen and Quevedo 1970, Echols 1975, Riley et al. 1979, Frank and Nikolai 1980, Peterson et al. 1982, Garner et al. 1986), and ligature force (Riley et al. 1979, Frank and Nikolai 1980). Friction is also influenced by: archwire shape (Riley et al. 1979, Frank and Nikolai 1980) and archwire material (Frank and Nikolai 1980, Peterson et al. 1982, Garner et al. 1986, Stannard et al. 1986, Popli et al., 1989). There is controversy regarding the influence of: bracket width (Nicholls 1968, Andreasen and Quevedo 1970, Frank and Nikolai 1980, Garner et al. 1986), lubrication (Andreasen and Quevedo 1970, Riley et al. 1979, Stannard et al. 1986, Baker et al. 1987) and surface roughness (Frank and Nikolai 1980, Garner et al. 1986, Stannard et al. 1986,

*Formerly postgraduate student, Orthodontic Department University of Melbourne; now Senior Registrar, Westmead Hospital, N.S.W.
+Assoc/Professor, Department of Orthodontics, University of Melbourne

Kusy and Whitley 1989). No data was found on multistranded stainless steel archwires.

The objectives of this study were:
(1) To determine and compare the effect of different cross-sectional archwire dimensions on friction
(2) To determine the effect of archwire-to-bracket angulation on friction
(3) To evaluate the surface roughness of the archwires and bracket slots by Scanning Electron Microscopy and relate this to the observed friction
(4) To determine and compare the effect on friction of different archwire and bracket compositions.
(5) To determine and compare the frictional resistance of multistranded stainless steel and single stranded beta-titanium and nickel-titanium archwires.
(6) To determine the influence of artificial saliva on friction.

MATERIALS AND METHODS

Twenty-six lower anterior edgewise stainless steel[1] and 26 ceramic[2] brackets with 0 degrees torque and angulation were subdivided into two groups of 13. One group was tested under dry conditions and the other with artificial saliva[3] (wet conditions).
Fifty-two archwires 75mm in length were tested:

Table 1: Archwires tested

Alloy/ Configuration	Product	Archwire size (X.001 inch)	Sample Size
Stainless steel/ Triple strand	Dentaflex[4]	16x16	4
Stainless steel Triple strand	Quad Cat[4]	16x16, 16x22, 17x25	4 of each size = 12
Stainless steeV Eight strand	Flex VIII[6]	16x16, 16x22, 17x25	4 of each size = 12
Nickel-titanium/ Single strand	Orthonol[7]	16x16, 16x22, 17x25	4 of each size = 12
Beta-titanium/ Single strand	TMA[8]	175x175,16x22,17x25	4 of each size = 12

Each group of four archwires were subdivided into two groups of two archwires. One group was tested under dry conditions and the other under wet conditions.

The brackets were cemented to the flat cut surfaces of fifty-two 1.30cm diameter stainless steel rods. Each bracket slot and archwire was cleaned to remove contaminants using ultrasonics and 99.7-100.0% v/v ethanol. This was confirmed microscopically. The wires were ligated to the brackets with Unitek's A1 elastic ligature rings. After a period of 6 days to allow the elastic ligature rings to reach a stable level of force (Tselepis 1989) each rod-wire-ligature assembly was inserted into the jaws of a metal collet device which was positioned on the platform of a Shimadzu universal testing machine[11]. A protractor was glued to the face of the collet such that its zero degrees mark was in line with the travel of the crosshead.

A pin vice was used to grip the end of the archwire. The pin vice was connected to a 50 Newton load cell by three links of a metal chain to allow for free movement in all planes of space (*Figure 1*).

A crosshead speed of 10mm/min was set. The universal testing machine was programmed to record the frictional force (Newtons) graphically and to calculate the mean force required to slide the archwire 2mm through the bracket. This was performed ten times at 0 degrees archwire-to-bracket angulation, over a total distance of 20mm. The experiment was repeated at 10 and 20 degrees angulation. In a separate series, artificial saliva was used as lubrication.

To eliminate the influence of wear on friction, the archwire and bracket were paired such that only one archwire was drawn through it's paired bracket.

In a separate investigation, each archwire type and size, and both types of brackets were examined under a Scanning Electron Microscope[12] (S.E.M.) between 60 and 1000 magnification. A detailed report of this is to be presented separately.

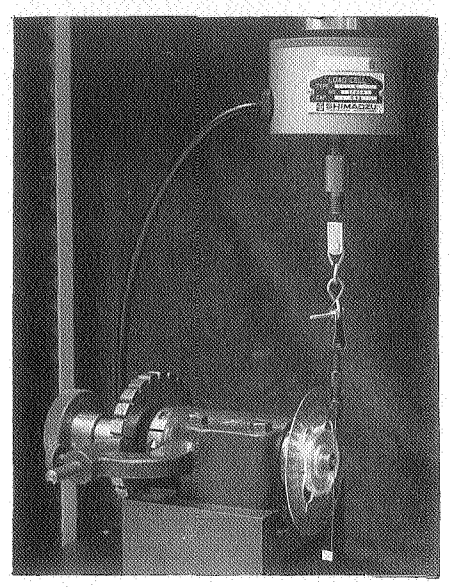


Figure 1. Apparatus used for study.

1. Dyna-lock Unitek Corp, Monrovia, Calif, USA.
2. Tomy. Tomy International, Tokyo, Japan
3. Oropharm Pty Ltd, Melbourne, Australia.
4. Dentauram, Pforzheim, FRG.
5. GAC International, New York, USA.
6&7. RMO, Denver, Colo, USA.
8. Ormco Corp, Glendora, Calif, USA.
9. Unitek Corp, Monrovia, Calif, USA.
10. Shimadzu Corp, Kyoto, Japan.
11. Hitachi Ltd, Tokyo, Japan
12. University of Melbourne Statistical Consulting Service, Australia

RESULTS

(1) There was a variation in the magnitude of friction within the various types of archwire. The order of ranking from least to most friction is: Dentaflex, Flex VIII, Quad Cat, Orthonol and TMA (*Figure 2*). Multistranded archwires showed significantly lower friction than single stranded archwires as shown by the non-overlapping confidence intervals (*Table 2*).

Table 2: Confidence intervals for friction (Newtons): Archwires

Wire	Sample Size	Mean	Confidence Interval 95%
Dentaflex	120	1.80	(1.75, 1.85)
Flex VIII	360	2.05	(2.02, 2.07)
Quad Cat	360	2.11	(2.08, 2.14)
Orthonol	360	3.37	(3.34, 3.40)
TMA	360	4.26	(4.24, 4.30)

(2) Stainless steel brackets gave lower friction than ceramic brackets.
(3) Wet conditions gave lower friction than dry conditions
(4) The ranking of angulations in terms of friction from least to most was: 0, 10 and 20 degrees (*Figures 2 and 3*).
(5) Within each archwire type, the effect of size differs, but 0.016x0.016 inch gave the lowest friction.
(6) The archwires were ranked in order of increasing surface roughness as: Orthonol; Flex VIII and Quad Cat; Dentaflex; TMA. The stainless steel bracket slots were smoother than those of ceramic brackets.

Table 3: Analysis of Variance (Newtons)

Source(s) of variation	d.f.	s.s.	m.s.	v.r.
Archwire (wire)	4	1.379E+03	3.447E+02	4481.34
Bracket	1	5.395E+02	5.395E+02	7013.87
Condition (Cond)	1	1.341E+01	1.341E+01	174.27
Angulation (angulation)	2	1.058E+03	5.290+02	6877.08
WirexSize	8	2.250E+02	2.812E+01	365.56
WirexBracket	4	5.550E+01	1.387E+01	180.26
WirexCond	4	9.069E+00	2.252E+00	29.27
BracketxCond	1	5.096E+00	5.096E+00	66.24
WirexAngle	8	6.374E+02	7.943E+01	1031.39
BracketxAngle	2	6.303E+01	3.151E+01	409.68
CondxAngle	2	1.338E+01	6.690E+00	86.98
WirexSizexBracket	8	1.135E+01	1.418E+00	18.44
WirexSizexCond	8	3.257E+01	4.071E+00	52.93
WirexBracketxCond	4	6.805E+00	1.701E+00	2.12
WirexSizexAngle	16	3.757E+01	2.348E+00	30.53
WirexBracketxAngle	8	4.793E+01	5.991E+00	77.88
WirexCondxAngle	8	2.240E+01	2.800E+00	36.40
BracketxCondxAngle	2	3.379E+00	1.698E+00	22.08
Residual	1468	1.129E+02	0.796E+01	
Total	1559	4.270E+03		

All variance ratios are large enough to be considered significant (P<0.001). This means that all factors and interactions have a statistically significant effect on friction.

d.f. = degrees of freedom s.s. = sums of squares m.s. = mean of squares v.r. = variance ratio

The figures below present a summary of the results. Note: the lines are to connect like samples, and do not indicate a trend.

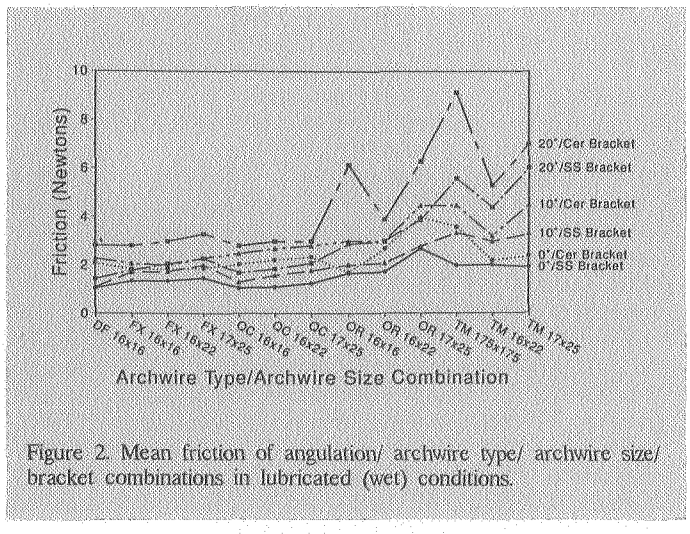


Figure 2. Mean friction of angulation/ archwire type/ archwire size/ bracket combinations in lubricated (wet) conditions.

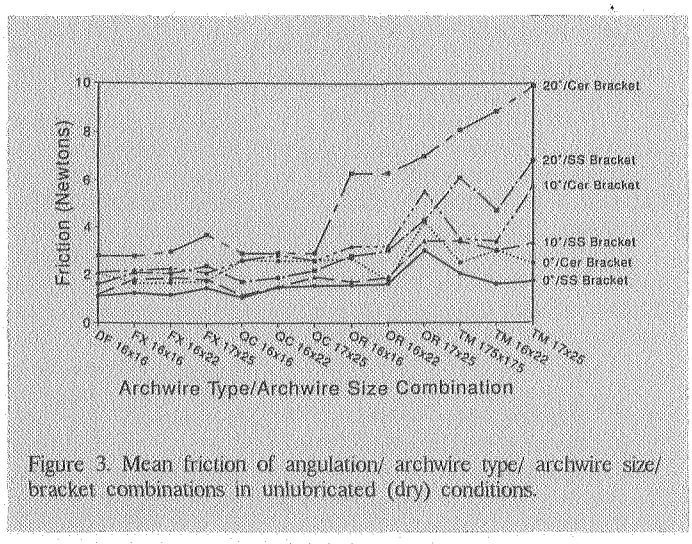


Figure 3. Mean friction of angulation/ archwire type/ archwire size/ bracket combinations in unlubricated (dry) conditions.

DISCUSSION

Archwires showed an increase in friction with increase in archwire size, with the exception of two Orthonol archwires size 0.016x0.022 inch (*Figures 2 and 3*). The S.E.M. examination indicated that these two archwires were marginally smoother than those of smaller size 0.016x0.016 inch and may explain the unusually low friction observed in the larger archwires. This was confirmed by additional tests. Also TMA 0.016x0.022 inch wire showed less friction than smaller sized 0.0175x0.0175 inch wire at all angulations/bracket combinations in wet conditions. This suggests that there may be a relationship between the vertical dimension of the archwires (the first dimension) and friction. This concurs with Frank and Nikolai (1980) and Drescher et al. (1989). Increased angulation produced a significant increase in friction for all measurements. This is in agreement with Nicholls (1968), Andreasen and Quevedo (1970), Frank and Nikolai (1980), Petersen et al. (1982). It appears that the greater the angulation, the greater the contact force between archwire and bracket. The increase in friction was greater for TMA and Orthonol compared to multistranded stainless steel archwires. This may be related to the differences in wire stiffness. The ranking of archwires in order of decreasing friction and surface roughness is

dissimilar. However, ceramic bracket slots which were rougher than those of stainless steel brackets showed greater friction for all measurements. Thus surface roughness appears to be an important factor in bracket slots but not so in archwires. The association between bracket slot surface roughness and friction although suspected in clinical practice, has not been previously reported. All archwire types gave significantly different amounts of friction. It was possible to rank the archwires in order of increasing friction Dentaflex, Flex VIII, Quad Cat, Orthonol and TMA. This suggests that the material used in the archwire affects friction.

Multistranded archwires induced significantly lower friction than single strand archwires. The lower friction may be explained in part by the fact that the multistranded wires are made of stainless steel and have a smoother surface than TMA. It is only possible to speculate on the effect of archwire stiffness on friction as no published data on rectangular multistranded archwires was found. In general lubrication significantly reduced friction. The most notable exceptions were several TMA archwires which showed increased friction in lubricated conditions. Because lubrication is an important factor in friction, it is proposed that future investigations should be conducted under lubricated conditions.

CONCLUSIONS

1. All five factors and 14 interactions tested showed statistically significant effects on friction.
2. Increase in archwire-to-bracket angulation produced a significant increase in friction for all measurements.
3. Increase in archwire size in most cases produced an increase in friction. Exceptions were some TMA archwires.
4. There was a definite relationship between friction and material used for archwire and bracket fabrication.
5. No definite relationship was found between archwire surface roughness and friction.
6. Friction increased with bracket slot surface roughness. Ceramic bracket slots which were rougher than stainless steel bracket slots, showed higher friction for all corresponding measurements.
7. Lubrication with artificial saliva significantly reduces friction.
8. The highest friction (9.95 Newtons) was recorded for the combination: TMA/0.0175x0.0175 inch/20 degrees/ ceramic brackets unlubricated conditions. The lowest friction (1.02 Newtons) was recorded for: Dentaflex/-0.016x0.016 inch/0 degrees/ stainless steel bracket/ with lubrication.
9. The magnitude of the friction recorded is substantially larger than the forces applied in orthodontic movement clinically. It is proposed that the values recorded should be utilized as a means of comparing the effects of different factors, rather than quantifying the friction in-vivo.

CLINICAL IMPLICATIONS

1. Sliding mechanics may be utilized with multistranded rectangular archwires during the initial phases of levelling and aligning, and the final seating of the occlusion.
2. At 0^{0} angulation, friction may not affect the sliding of TMA and Orthonol archwires adversely; hence the need for excellent levelling prior to retraction.
3. Retarded tooth movement and increase in anchorage requirements are possible consequences of treatment when ceramic brackets are used with sliding mechanics.

Acknowledgment

The authors wish to thank the Australian Society of Orthodontists' Foundation for Research and Education for the grant awarded for this study.

REFERENCES

ANDREASEN,G.F., and MARIS,A.A. (1969)
The Rolamite bracket: A preliminary discussion of frictionless tooth movement
J.Biomechanics 2:199-201
ANDREASEN,G.F. and QUEVEDO,F.R. (1970)
Evaluation of friction forces in the 0.022x0.028 inch edgewise bracket in-vitro
J.Biomechanics 3:151-160
ANDREASEN,G.F. and ZWANZIGER,D. (1980)
A clinical evaluation of the differential force concept as applied to the edgewise bracket
Am.J.Orthod.78:25-40
BAKER,K.L.,NIEBERG,L.G.,WEIRNER,L.D. and HANNA,M. (1987)
Frictional changes in force values caused by saliva substitution
Am.J.Orthod.Dentofac.Orthop.91:316-320
CREEKMORE,T.D. (1976)
The importance of interbracket width in orthodontic tooth movement
J.Clin.Orthod.10:530-534
DRESCHER,D., BOURAUEL,C. and SCHUMACHER,H.A. (1989)
Frictional forces between bracket and archwire
Am.J.Orthod.Dentofac.Orthop.96:397-404
ECHOLS,P.M. (1975)
Elastic ligatures: Binding forces and anchorage taxation
Am.J.Orthod.67:219-220
FRANK,C.A. and NICOLAI,R.J. (1980)
A comparative study of frictional resistances between orthodontic bracket and archwire
Am.J.Orthod.78:593-609
GARNER,L.D.,ALLAI,W.W. and MOORE,B.K. (1986)
A comparison of frictional forces during simulated canine retraction on a continuous edgewise archwire
Am.J.Orthod.Dentofac.Orthop.90:199-203
GOTTLIEB,E.L.,WILDMAN.A.J.,HICE,T.L.,LANG,M.,LEE,I.F. and STRAUCH,E.C. (1972)
The edgelok bracket
J.Clin.Orthod.6:613-623
KAMIYAMA,T. and SASAKI,T. (1973)
Friction and width of brackets
J.Japan Ortho Soc.32:286-289
KAPILA,S. and SACHDEVA,R. (1989)
Mechanical properties and clinical applications of orthodontic wires
Am.J.Orthod.Dentofac.Orthop.96:100-109
KUSY,R.P. and WHITLEY,J.Q. (1989)
Effects of sliding velocity on frictional coefficients of archwires
J.Dent.Res.68:275, Special Issue:15-19
KUSY,R.P.,Whitley.J.D.,Mayhew.M.J. and BUCKTHAL.J.E. (1988)
Surface roughness of orthodontic archwires, via laser spectroscopy
Angle Orthod.58:33-45
NICHOLLS,J. (1968)
Frictional forces in fixed orthodontic appliance
Dent.Practit.18:362-366
PETERSON,L.,SPENCER,R. and ANDREASEN,G. (1982)
A comparison of friction resistance for nitinol and stainless steel wire in edgewise brackets
Quintessence International, No 5 pp1-9
POPLI,K.,PRATEEN,D.,GERMANE,N. and GUNSOLLEY,J. (1989)
Frictional resistance of ceramic and stainless steel orthodontic brackets
J.Dent.Res.68:275 Special Issue pp15-19
RICKETTS,R.M.,BENCH.R.W.,GUGINO,C.F.,,HILGERS,J.J. and SCHULHOF,R.J. (1986)
Bioprogressive Therapy Book I Denver, Colorado: Rocky Mountain Orthodontics
RILEY,J.L.,GARRET.S.G. and MOON,P.C. (1979)
Frictional forces of ligated metal and edgewise brackets
J.Dent.Res.58:A21 IADR Abstract p98

ROCK,W.P. and WILSON,H.I. (1989)
The effect of the bracket type and ligation method upon the forces exerted by orthodontic archwire
Brit.J.Orthod.16:213-217
STANNARD,J.G.,GAU,J.M. and HANNA,M.A. (1986)
Comparative friction of orthodontic wires under dry and wet conditions
Am.J.Orthod.89:485-491
STONER,M.M. (1960)
Force control in clinical practice
Am.J.Orthod.46:163-186
THUROW,R.C, (1975)
Edgewise Orthodontics
3rd ed. St Louis C.V.Mosby Co.
TIDY,D.C. (1989)
Frictional forces in fixed appliances
Am.J.Orthod.Dentofac.Orthop.96:249-254
TSELEPIS,M. (1989)
Frictional resistance between orthodontic brackets and archwires
M.D.Sc. Thesis University of Melbourne

Correspondence to:
Assoc/Professor V.C.West
Department of Orthodontics
The Royal Dental of Melbourne
711 Elizabeth Street
MELBOURNE
Victoria 3000.