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Research Article

FRICTION BETWEEN PRE-ADJUSTED EDGEWISE STAINLESS STEEL BRACKETS AND ORTHODONTIC WIRES. - AN IN-VITRO STUDY

Sanjeev Jakati[1]*., SuryaprakashVijayvargia[2] and RadhakrishnaGogineni[3]

[1]Department of orthodontics, Swargiya Dadasaheb Kalmegh Smruti Dental College & Hospital Nagpur India
[2]Private Practitioner Surat Gujrat
[3]Department of orthodontics, PMNM DCH Bagalkot India

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ABSTRACT

Introduction: During Canine retraction and space consolidation, biologic tissue response and tooth movement occur only when applied forces adequately overcome the friction at bracket-wire interface. Today, many clinicians prefer to use wires of alloys such as Stainless steel, Nickel-titanium, or Beta-titanium during different phases of treatment. To deliver optimal forces for efficient and predictable tooth movement, it is necessary to have both an assessment and knowledge of forces required to overcome friction when different wire sizes and materials are used.

Materials & Methods: Frictional force of Stainless steel, Nickel-titanium and Beta-titanium wires of different sizes will be tested in stainless steel pre-adjusted edgewise MBT premolar brackets. Brackets will be attached to special jig and wires will be ligated with elastomeric ligatures. Bracket movement along the wire will be implemented by an Instron universal testing machine, and frictional forces will be measured by a compression cell and recorded on an X-Y recorder. Frictional forces generate by each bracket-wire subsample will be subjected to statistical analysis. Interactive effects of wire size and alloys type on magnitude of bracket-wire friction will be assessed by two-way analysis of variance.

Results &Conclusion: Sliding mechanics can best be performed using stainless steel archwire. Wire alloy could be ranked in order from lowest to highest friction: Stainless steel, Nickel-titanium and Beta-Titanium irrespective of wire and slot sizes. Frictional force increases with increase wire sizes in both 0.018 and 0.022 slot in all three kind of archwire alloys. Slotsize does not tend to have a significant effect on friction, but more importantlyrelative size of archwire within bracket slot will have a significantinfluence.

INTRODUCTION

Over the past century, improvements in mechanotherapy and treatment philosophy have led to major advancements in orthodontic patient care. Orthodontic tooth movement is dependent on ability of clinician to use controlled mechanical forces to stimulate biologic responses within periodontium (Rossouw PE 2003). Application of proper magnitude of force during orthodontic treatment will result in optimal tissue response and rapid tooth movement (Schwartz AM 2003, Rossouw PE 2003). But a biologic tissue response with resultant tooth movement will occur only when applied forces adequately overcome friction at bracket wire interface (Kapila S *et al* 1990).

Space closure in straight wire appliance entails moving the teeth by sliding preadjustededge wise brackets over a continuous archwire-ligature assembly (sliding mechanics) or by mobilizing them with help of loops (loop mechanics). During retraction of anteriors with sliding mechanics, a significant amount of applied force is lostin process of overcoming frictional resistance offered by wire-bracket ligature assembly (Kapila S *et al* 1990).

Friction is a force that retards or resists relative motion of two objects in contact. Direction of friction is tangential to common boundary of two surfaces in contact (Morris W 1969). Static frictional force is smallest force needed to start motion of solid surfaces that were previously at rest with each other, whereas Kinetic frictional force is force that resists sliding motion of one solid object over another at a constant speed. As tooth

Corresponding author:* ***Sanjeev Jakati*
Department of orthodontics, Swargiya Dadasaheb Kalmegh Smruti Dental College & Hospital Nagpur India

moves in the direction of applied force, kinetic friction occurs between bracket and archwire (Rossouw PE 2003).

Friction is thus a challenging entity and has to be dealt with efficiently in order to obtain a favourable outcome (Rossouw PE 2003). Minimization of this frictional resistance during retraction allows most of applied force to be transferred to teeth thus optimizing orthodontic tooth movement and decreasing undesirable anchorage loss. However, not all friction in orthodontic appliance is detrimental to tooth movement. This very same bracket-archwire binding becomes essential for maintaining anchor-units or uprightingangulated teeth (Rossouw PE 2003). Hence, knowing friction generated in a specific combination of bracket and wire allows clinician to make adjustments in appliance in order to either generate or overcome friction in response to specific clinical requirements. Thus, it is not desirable to discard friction altogether from appliance system. In such a scenario, it becomes imperative for clinician to have an in-depth understanding of characteristics of orthodontic appliance and factors determining this friction (Frank CA, and Nikolai W 1980). The only way in which friction can be effectively regulated clinically is by maximizing both efficiency and reproducibility of orthodontic appliance (Kusy RP, Whitley JQ 1997).

Friction generated by interaction of an archwire and bracket is influenced by variables such as bracket composition, bracket width, interbracket distance, slot size, archwire type, archwire size, second order angulation, degree of torsion, ligation, and whether environment is wet or dry (Rossouw PE 2003).

Commonly used wires belong to stainless steel, nickel-titanium and beta-titanium alloys. An understanding of interplay of these wires in different sizes and bracket type aids in delivering optimal forces for efficient and predictable tooth movement.

To help clinical decision-making in this aspect of mechanotherapy, in-vitro studies in which fixed appliances are simulated and interplay between various factors are independently analyzed have become invaluable. Based on this, study was designed to determine effects of wire size and wire materials on frictional force generated between bracket and wire during in-vitro translatory displacement of bracket relative to wire.

Aims and Objective of study

1. To determine and compare effects of different archwire materials Viz., stainless steel, nickel-titanium and beta-titanium on coefficient of friction in 0.018 inch slot &0.022 inch slot preadjusted edgewise stainless steel MBT brackets.
2. To determine and compare effects of different archwire sizes i.e., 0.017 X 0.025 and 0.018 X 0.025 inch on coefficient of friction in 0.018 inch slot, 0.017 X 0.025, 0.019 X 0.025 and 0.021 X 0.025 inch on coefficient of friction in 0.022 inch slotpreadjusted edgewise stainless steel MBT brackets.
3. To compare coefficient of friction between 0.018 and 0.022 inch slotpreadjusted edgewise stainless steel MBT brackets with respect to 0.017 X 0.025 inch archwire of stainless steel, nickel-titanium and beta-titanium.

METHODOLOGY

Frictional force generated bystainless steel, nickel-titanium and beta-titaniumwires of different sizes were tested in stainless steel pre-adjusted edgewise MBT maxillary premolar brackets in 0.018 and 0.022 inch slotsizes.(3M Unitek Gemini series).Wire sizes tested in both 0.018 and 0.022 slotsizes were grouped as follows

Group 1 – 0.018 inch slot stainless steel MBT maxillary premolar bracket

Sub group A – 30 samples of 0.017 × 0.025 inch wires of all three alloys each

Sub group B – 30 samples of 0.018 × 0.025 inch wires of all three alloyseach

GROUP 2 – 0.022 inch slot stainless steel MBT maxillary premolar bracket

Sub group A – 30 samples of 0.017 × 0.025 inch wires of all three alloyseach

Sub group B – 30 samples of 0.019 × 0.025 inch wires of all three alloyseach

Sub group C – 30 samples of 0.021 × 0.025 inch wires of all three alloyseach

An experimental model simulating fixed appliance was prepared for measuring friction between archwire and bracket combinations, (Figure 1/ schematic diagram) An 0.018 X 0.025 inch stainless steel archwire of approximately 10 cm length was taken, which was inserted and tied into slots of five 0.018 inch slot maxillary premolar brackets with Leone™ elastomeric rings, such that brackets were spaced at an interval of 8 mm from each other.(Figure 2) A similar set-up was created for 0.022 inch slot brackets using an 0.021 X 0.025 inch stainless steel straight wire as base wire. (Figure 3). When dealing with friction the methodology using elastomeric ligation is not the best choice but still it is preferredin order to reduce the patient's chairside time while using stainless steel ligature ties.

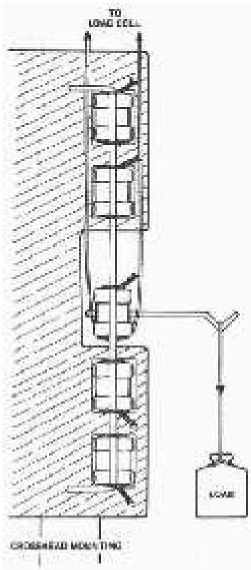

Fig 1 schematic diagram

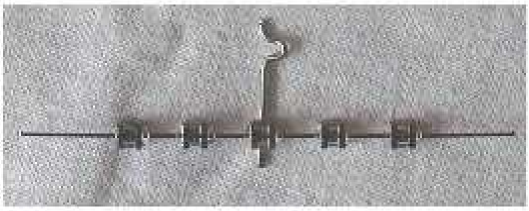

Figure 2: Five 0.018 inch slot brackets algined along an 0.018 X 0.025 inch stainless steel base archwire

Figure 3: Five 0.022 inch slot brackets algined along an 0.021 X 0.025 inch stainless steel base archwire

To the bracket in the centre, a 10 mm power arm was soldered to the base, which represented distance of slot from centre of resistance of tooth. From this power arm, a weight of 100 grams was suspended, this set-up thus represented the single equivalent force acting at centre of resistance of tooth undergoing retraction. (Figure 4)

Figure 4: 100 gram weight to be attached on power arm of central bracket

A rigid acrylic Perspex sheet measuring 15 X 7.5 X 0.4 cm in size was taken. On one end along its length, a 16 X 16 mm block of acrylic from the edge was cut away. (Figure 5) Five brackets and archwire assembly was then fixed onto this sheet with an adhesive, such that central bracket with power arm was in centre of 16 X 16 mm space of Perspex sheet, free to slide along the archwire. (Figure 6)

Figure 5: Rigid acrylic Perspex sheet with a 16 X 16 mm cut out along one side

Figure 6: Experimental set-up for Fixed appliance simulation

Measurement of frictional force between different bracket-archwire combinations was obtained using Instron universal testing machine. (Figure 7 and 8) Lower end of Perspex sheet assembly was fixed to stationary lower jaw of universal testing machine. A ligature wire loop was created, one end of which went around bracket in centre, other end being hooked to cross-head in movable upper jaw of Instron machine. (Figure 1) This cross-head was moved in upper direction at a rate of 5 mm/min over a distance of 3 mm, which caused central bracket to slide along archwire. (Figure 9 and 10)

Figure 7: Instron Universal testing machine assembly

Figure 8: Upper and lower force loading arm of Universal testing machine

Figure 9: 0.018 inch slot set-up being tested

Figure 10: 0.022 inch slot set-up being teste

Force required to bring about this slide was recorded through load-cell reading. Load cell reading represents total amount of force applied to a tooth, to bring about tooth movement, part of which is spent in overcoming frictional resistance and remainder is harnessed to cause tooth movement. In other words, load cell reading represented clinical force of retraction that would be applied to tooth, part of which would be lost in friction while remainder would be transmitted to tooth root. Thus, difference between load cell reading and load on power arm represented force required to over-come friction.

Keeping basic set up the same for both slot sizes, friction generated by different archwire sizes in different materials was progressively measured. All tests were conducted in dry conditions. Each wire sample was tested only once to eliminate possibility of surface wear effects, resulting in 450 wire specimens being tested totally between both slots.

A load-deflection graph was plotted during each test by using Bluehill software on a computer, where X-axis represented bracket movement in millimetres, and Y-axis recorded load in grams. Difference between load-cell reading and load on power arm was frictional force.Load on power arm of central bracket (F) subtracted from load cell reading gave magnitude of frictional force resistance (P) from which coefficient of friction (µ) was calculated using Tidys formula (Tidy DC 1980) $P = 2Fh\mu / w$, where 'w' is width of bracket and 'h' is distance from archwire to load application.

Statistical Analysis

Data obtained was subjected to statistical analysis using IBM-SPSS (Statistical Package of Social Software, version 22.0). Descriptive statistics including mean and standard deviation were calculated for all groups& subgroups.

Significance for all statistical tests was set at $p \leq 0.05$.

RESULTS

Mean Values of Coefficient of Friction for Each Archwire Size In All Three Materials In Both Slots

Mean values and SDof coefficient of friction of beta-titanium wire was found to be highest for all wire sizes in both 0.018 and 0.022 inch slot followed by nickel-titanium wire and least with stainless steel wires. (Table 1)

Table 1

Slot size (inches)	Wire size (inches)	Wire alloy	Mean	Std Deviation
0.018 Slot	0.017 × 0.025	Stainless steel	0.2562	0.005974
		NiTi	0.3423	0.014181
		Beta-Titanium	0.434	0
	0.018 × 0.025	Stainless steel	0.32963	0.008426
		NiTi	0.46993	0.007301
		Beta-Titanium	0.56403	0.007636
0.022 Slot	0.017 × 0.025	Stainless steel	0.09597	0.010965
		NiTi	0.12873	0.010891
		Beta-Titanium	0.16853	0.008897
	0.019 × 0.025	Stainless steel	0.19083	0.006998
		NiTi	0.2705	0.010119
		Beta-Titanium	0.3802	0.008511
	0.021 × 0.025	Stainless steel	0.3413	0.01117
		NiTi	0.4392	0.007332
		Beta-Titanium	0.53067	0.011158

Comparison between Three Materials at Each Archwire Size In Each Slot

Coefficient of friction of 0.017 × 0.025& 0.018 × 0.025 incharchwire in 0.018 inch slot in all three materials was compared using one-way ANOVA test. (Table 2)

In 0.022 inch slot coefficient of friction of all three materials at each archwire size i.e. 0.017 × 0.025, 0.019 × 0.025 and 0.021 × 0.025 inch were compared using one-way ANOVA test. (Table 2)

Post hoc Tukey – HSD multiple comparison test was carried out to detect significant differences between three sub-groups of materials in each group at each archwire size. Again a statistically significant difference between all sub-groups in both 0.018 and 0.022 inch slots at 'P' value lower than 0.001 was obtained. (Table 3)

It was observed that beta-titanium archwires had highest coefficient of friction in all three sizes and in both slot sizes followed by nickel-titanium archwires and then by stainless steel wires, with difference between them being statistically significant. **(Table 2-3)**

Comparison between Different Archwire Sizes In Each Material Category And Each Slot

0.018 inch slot

Stainless steel, nickel-titanium, beta-titanium archwires at sizes of 0.017 × 0.025 and 0.018 × 0.025 inch were compared with each other using a T test. It was found that coefficient of friction of 0.018 × 0.025 incharchwire in all three materials was greater than corresponding 0.017 × 0.025 inch archwire in each material, with difference being statistically significant. (Table 4)

0.022 inch slot

In each of three material groups three wire sizes of 0.017 × 0.025, 0.019 × 0.025 and 0.021 × 0.025 inch were compared with each other using a one-way ANOVA test. (Table 5)After a statistical significant difference was observed, post hoc analysis of sub-groups using Tukey HSD multiple comparison test was carried out. (Table 6)

Results proved that coefficient of friction of 0.021 × 0.025 inch archwire was highest followed by 0.019 × 0.025 inch and then by 0.017 × 0.025 wire sizes between all three materials, to be statistically significant. (Table 5-6)

Table 2

Slot size (inches)	Wire size (inches)	Wire alloy	N	Mean	SD	Mean Square	F	Sig.
0.018 Slot	0.017×0.025	Stainless steel	30	0.256	0.005	0.237	3004.79	<0.001
		NiTi	30	0.342	0.014			
		Beta-Titanium	30	0.434	0			
	0.018×0.025	Stainless steel	30	0.329	0.008	0.417	6857.28	<0.001
		NiTi	30	0.469	0.007			
		Beta-Titanium	30	0.564	0.008			
0.022 Slot	0.017×0.025	Stainless steel	30	0.096	0.011	0.04	373.74	<0.001
		NiTi	30	0.129	0.011			
		Beta-Titanium	30	0.169	0.009			
	0.019×0.025	Stainless steel	30	0.191	0.007	0.271	3635.28	<0.001
		NiTi	30	0.270	0.010			
		Beta-Titanium	30	0.380	0.009			
	0.021×0.025	Stainless steel	30	0.341	0.011	0.269	2663.64	<0.001
		NiTi	30	0.439	0.007			
		Beta-Titanium	30	0.531	0.011			

Table 3

Tukey HSD Multiple Comparison Test						
Slot size (inches)	**Wire size (inches)**	**Wire alloy**	**Wire alloy**	**Mean Difference**	**Std. Error**	**Sig.**
0.018 Slot	0.017×0.025	Stainless Steel	NiTi	-.086100	.0023	**<0.001**
		Stainless Steel	ß-Titanium	-.177800	.0023	**<0.001**
		NiTi	ß-Titanium	-.091700	.0023	**<0.001**
	0.018×0.025	Stainless Steel	NiTi	-.140300	.0021	**<0.001**
		Stainless Steel	ß -Titanium	-.234400	.0020	**<0.001**
		NiTi	ß -Titanium	-.094100	.0020	**<0.001**
0.022 Slot	0.017×0.025	Stainless Steel	NiTi	-.032767	.0026	**<0.001**
		Stainless Steel	ß -Titanium	-.072567	.0026	**<0.001**
		NiTi	ß -Titanium	-.039800	.0026	**<0.001**
	0.019×0.025	Stainless Steel	NiTi	-.079667	.0022	**<0.001**
		Stainless Steel	ß -Titanium	-.189367	.0022	**<0.001**
		NiTi	ß -Titanium	-.109700	.0022	**<0.001**
	0.021×0.025	Stainless Steel	NiTi	-.097900	.0025	**<0.001**
		Stainless Steel	ß -Titanium	-.189367	.0025	**<0.001**
		NiTi	ß -Titanium	-.091467	.0025	**<0.001**

Table 4

Wire alloys	Wire sizes (inches)	N	Mean	Std. Deviation	T	Df	Sig. (2-tailed)
Stainless steel	0.017×0.025	30	0.2562	0.0059735	-38.941	52.272	<0.001
	0.018×0.025	30	0.329633	0.0084261			
NiTi	0.017×0.025	30	0.3423	0.0141815	-43.828	43.364	<0.001
	0.018×0.025	30	0.469933	0.0073011			
Beta-Titanium	0.017×0.025	30	0.434	<10 E-7	-93.271	29	<0.001
	0.018×0.025	30	0.564033	0.007636			

Table 5

Wire alloys	Wire sizes (inches)	N	Mean	Std. Deviation	Mean Square	F	Sig.
Stainless steel	0.017×0.025	30	0.095967	0.010965	0.459	4685.431	<0.001
	0.019×0.025	30	0.190833	0.006998			
	0.021×0.025	30	0.3413	0.01117			
NiTi	0.017×0.025	30	0.128733	0.010891	0.725	7912.982	<0.001
	0.019×0.025	30	0.2705	0.010119			
	0.021×0.025	30	0.4392	0.007332			
Beta-Titanium	0.017×0.025	30	0.168533	0.008897	0.993	10788.63	<0.001
	0.019×0.025	30	0.3802	0.008511			
	0.021×0.025	30	0.530667	0.011158			

Table 6

Tukey HSD Multiple Comparisons test					
Wire material	**Wire size (inches)**	**Wire size (inches)**	**Mean Difference**	**Std. Error**	**Sig.**
Stainless steel	0.017×0.025	0.019×0.025	-.0948667	.0025560	<0.001
		0.021×0.025	-.2453333	.0025560	<0.001
	0.019×0.025	0.021×0.025	-.1504667	.0025560	<0.001
NiTi	0.017×0.025	0.019×0.025	-.1417667	.0024710	<0.001
		0.021×0.025	-.3104667	.0024710	<0.001
	0.019×0.025	0.021×0.025	-.1687000	.0024710	<0.001
Beta-Titanium	0.017×0.025	0.019×0.025	-.2116667	.0024770	<0.001
		0.021×0.025	-.3621333	.0024770	<0.001
	0.019×0.025	0.021×0.025	-.1504667	.0024770	<0.001

Comparison of coefficient of friction between 0.018 and 0.022 inch slot brackets at a single archwire size in all three materials

Coefficient of friction of 0.017 × 0.025 inch archwire in 0.018 and 0.022 inch slot of each material was compared using a T test. (Table 6)

Statistically significant difference was obtained between two slots and was observed that coefficient of friction of 0.017 × 0.025 incharchwire between all three materials was greater in 0.018 inch slot than 0.022 inch slot. (Table 7)

DISCUSSION

Preadjusted edgewise appliance system was a revolutionary breakthrough in orthodontics. It simplified fixed mechanotherapy and clinical procedures by reducing need for wire bending. While sliding the archwire through brackets in the form of friction, hinders smooth tooth movement due to interaction between brackets, archwires and ligatures (Southard TE *et al* 2007).

Frictional forces act in adirection tangential to plane of contact between bracket and archwire and oppose sliding motion of tooth along archwire. This force is proportional to normal force transmitted across the plane of contact (Rossouw PE 2003). Friction reduces efficiency of fixed appliances during space closure which results in the need for applying more force to achieve desired results. Since light physiologic forces are more desirable for conserving anchorage, keeping reciprocal forces low, facilitating easy release of binding forces, improving patient comfort and reducing risk of root resorption (Mclaughlin RP *et al* 2001), orthodontist has to strive to apply low forces after overcoming friction.

However in a study by Bazakidou *et al* 1997 it was observed that nickel-titanium had more friction than beta-titanium and in a study by Prososki *et al* 1991 it was found that stainless steel

Table 7

Wire alloy	Slot size (inches)	N	Mean	Std. Deviation	T	Df	Sig. (2-tailed)
Stainless steel	0.018 Slot	30	0.2562	0.005974	70.284	44.819	**<0.001**
	0.022 Slot	30	0.095967	0.010965			
NiTi	0.018 Slot	30	0.3423	0.014182	65.419	58	**<0.001**
	0.022 Slot	30	0.128733	0.010891			
Beta-Titanium	0.018 Slot	30	0.434	0.00E-07	163.431	29	**<0.001**
	0.022 Slot	30	0.168533	0.008897			

Investigative methods used to study frictional resistance can be divided into four groups according to type of set up used (Pizzoni L *et al* 1998).

1. Archwire sliding through flat contacts, limiting the study to influence of materials only, Where archwire is sliding between two parallel plates hold in a universal testing machine (Kusy RP *et al* 1989).
2. Archwire sliding through brackets parallel to bracket slot, allowing analysis of influence of material, bracket design and wire dimension in addition to impact of saliva and different types of ligation (Downing *et al* 1995).
3. Archwire sliding through bracket with different second and third order angulations, allowing study of influence of variation in interbracket configuration (Frank CA, and Nikolai W 1980, Tselepis M *et al* 1994).
4. Studies designed in which brackets submitted to force were allowed a certain freedom of tipping, resulting in a retarding of applied force in an attempt to simulate impact of biological resistance to tooth movement (Ireland AJ *et al* 1991, Bednar JR *et al* 1991).

Protocol used in this study tried to closely approximate clinical situation. Measurements of friction between bracket, archwire and elastomeric ligature were done with apparatus that simulated fixed appliance in mouth with archwireheld in a vertical position. Each sample of wire was run on Intsron Universal testing machine, only once to eliminate surface wear effects. Coefficient of friction is approximately constant for any given pair of materials. In present study setup, it was postulated that, bracket alignment and ligation was a controlled constant, degree of friction generated at ligature-wire-bracket interface was affected by type of archwire alloy and sizes used.

Effect of Archwire Materials on Friction

Beta-Titanium

In present study beta-titanium has highest coefficient of friction. Pair wise comparison using post hoc analysis-Tukey HSD multiple comparison tests revealed that there was statistical significant difference between three archwire alloys with beta-titanium having highest coefficient of friction. (Table 1&2)

This study was in agreement with studies by Kapila S *et al* 1990, Drescher D *et al* 1989, Angolkar PV *et al* 1990, Garner LD *et al* 1986, Tidy DC 1990, Kusy RP *et al* 1991, Vaughan JL *et al* 1995, Nishio C *et al* 2004, Doshi UH *et al* 2011and Kao CT *et al* 2006 who found beta-titanium to have highest frictional resistance amongst all other alloys.

and beta titanium had highest frictional force values. Beta-titanium was found to exert greater friction when compared to stainless steel and nickel-titanium due to adhesion of beta-titanium archwire material to brackets (Kapila S *et al* 1990, Drescher D *et al* 1989, Garner LD *et al* 1986, Kusy RP *et al* 1991, Prososki RR *et al* 1991). Some investigators have stated that beta-titanium archwires should be avoided whenever sliding mechanics is required. With laser spectroscopy, stainless steel appeared smoothest, followed by beta-titanium and nickel-titanium (Prososki RR *et al* 1991). Despite fact that laser spectroscopy has found surface of beta-titanium to be smoother than nickel-titanium (Saunders CR *et al* 1994), most studies show that beta-titanium wires generate more friction than nickel-titanium wires (Kapila S *et al* 1990, Drescher D *et al* 1989, Angolkar PV *et al* 1990).

From a clinical context this helps the clinicians to deliberate that beta-titanium wires due to their higher frictional coefficient allow for less play between wire & bracket slot. Whether friction is a bone or boon to orthodontics is a topic of debate but with respect to friction generated among different archwires it is safe to predict that beta titanium wires are most recommended for torque application & during finishing stages of treatment especially with sliding mechanics.

Nickel-Titanium

Has more coefficient of friction compared to stainless steel but lesser than beta-titanium. In present study mean value of coefficient of friction of nickel-titanium was statistically more than stainless steel and less than beta-titanium as revealed by post hoc analysis-Tukey HSD multiple comparison test. It was found with pair wise comparison using post hoc analysis-Tukey HSD multiple comparison test that there was statistical significant difference between three archwire alloys with stainless steel having lowest coefficient of friction. (Table1&2) Similar finding were reported in studies like Kapila S *et al* 1990, Drescher D *et al* 1989, Angolkar PV *et al* 1990, Garner LD *et al* 1986, Tidy DC 1989, Kusy RP *et al* 1991, Vaughan JL *et al* 1995, Nishio C *et al* 2004, Doshi UH *et al* 2011 and Kao CT *et al* 2006 which suggest that significantly lower friction with nickel-titaniumwires than with beta-titaniumwires and higher than stainless steel archwires. Studies like Peterson L *et al* 1982, and Prososki RR *et al* 1991, suggest nickel-titanium produced least amount of friction, followed by stainless steel and then beta-titanium wires. Whereas studies like De Franco DJ 1995, Omana HM *et al* 1992, Peterson L *et al* 1982, Ireland AJ *et al* 1991, Loftus BP *et al* 1999, Cacciafesta V *et al* 2003 and Tselepis M *et al* 1994 suggested that no significant difference in levels of friction between stainless steel and nickel-titaniumarchwires.

This variability is due to differences in experimental settings and acquisition systems (Drescher D *et al* 1989), different point of force application (Tanne K *et al* 1991), and differentangulation between bracket and wire, which inmany studies is not zero (Ireland AJ *et al* 1991, Kusy RP *et al* 1991). From a clinical context this property of Nickel titanium archwires helps the clinician during alignment of teeth in the initial stages of orthodontic therapy without compromising the strength of the appliance which is impossible with stainless steel wire (because of its stiff nature).

Stainless steel

Has lowest coefficient of friction compared to other two alloys in this study. (Table 1&2) This finding were in support to studies like Kapila S *et al* 1990, Drescher D *et al* 1989, Angolkar PV *et al* 1990, Garner LD *et al*,[18] Tidy DC 1986, Kusy RP *et al* 1991, Vaughan JL *et al* 1995, Nishio C *et al* 2004, Doshi UH *et al* 2011 andKao CT *et al* 2006.

Effect of Wire Size on Friction

In both 0.018 and 0.022 inch slot as wire size increased friction increases irrespective of archwire alloys.(Table1)Similar findings were reported in studies done on effect of wire size on coefficient of friction, which include by Kapila *et al* 1990, Frank *et al* 1980,Drescher *et al* 1989, Angolkar *et al* 1990, Garner *et al* 1986, Peterson *et al* 1982, Andreasen *et al* 1970, Baker *et al* 1987, Echols 1975, Tanne *et al* 1991, Prososki *et al* 1991, and Taylor *et al* 1996.

Reason behind friction increases with increasing wire sizewas postulated by Frank and Nikolai[6]that with increase in wire sizes, stiffness of wire increased which in turn increases friction.

Of all dimensions, vertical or occluso-gingival height of wire plays most important role in determining friction. Friction increases with increase in vertical dimension of archwire. This factor can be regulated based on clinical requirement like when braking mechanics is required. Clinically a bracket responds to sliding process with increased friction, braking if vertical dimension of archwire is increased only minimally or archwire play in the bracket is decreased (Frank CA *et al* 1980, Drescher D *et al* 1989, Angolkar PV *et al* 1990, Ireland AJ *et al* 1991, Peterson L *et al* 1982, Andreasen GF *et al* 1970). However, Tidy *et al* 1989 found wire and slotsize had no effect on frictional force and that a reduction in wire size and subsequent reduction in wire stiffness, **c**linically permits greater tipping and hence an increase in binding (Drescher D *et al* 1989, Baker KL *et al* 1987).

Effect of Slot Size on Friction

A wire of same size was found to produce more friction in 0.018 inch slot as compared to 0.022 inch slot as seen in coefficient of friction values (Table 7)

Same observation was made in studies like Andreasen and Quevedo *et al* 1970 and Rock and Wilson *et al* 1989. They suggested that clinically frictional resistance decreased as slot size increased from 0.018 inch to 0.022 inch due to reduced binding of wire to bracket slot. Based on a mathematical model, Kusy and Whitley *et al* 1999 suggested that smaller brackets slots compared to larger bracket slots causes more binding to occur if initial alignment and levelling are not precise enough. Other investigators found slot size to have no influence on frictional resistance (Kusy RP *et al* 1989, Drescher D *et al* 1989).

It appears that there is no conclusive evidence that slot size significantly affects frictional resistance to sliding at archwire-bracket interface. However clinically what is more important, is size of archwire relative to slot, which has greater impact on frictional resistance. Consequently, as wire size increases, wire occupies more of slot leading to greater friction. Clinically, Maximally filling the slot leads to greater control of tooth due to severe binding, whereas minimally filling slot leads to poor control with relatively little binding (Kusy 2000). This is postulated in studies by Kusy 2000 which supports finding of our study that for a given wire size, irrespective of material, friction is greater in a smaller slot.

CONCLUSION

This *in-vitro* study evaluated the effect of three different archwire materials like stainless steel, nickel-titanium and beta-titanium, effect of variation in sizes of archwire and effect of bracket slot size on friction. Study was carried out on a simulated fixed appliance model on lines used by Tidy1989 under dry condition.

From results of this present study following clinical conclusions can be drawn:

1. Sliding mechanics can best be performed using stainless steel archwire. Wire alloy could be ranked in order from lowest to highest friction: Stainless steel, Nickel-titanium and Beta-Titanium irrespective of wire and slot sizes.
2. Frictional force increases with increase wire sizes in both 0.018 and 0.022 slot in all three kind of archwire alloys.
3. Slotsize does not tend to have a significant effect on friction, but more importantly relative size of archwire within bracket slot will have a significant influence.

This study was limited to *in vitro* condition at a simulated buccal segment model in dry environment. Further studies are required in vivo environment, as conditions *in vitro* differ from *in vivo* conditions with variables such as saliva, masticatory forces, temperature etc.

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