A Comparative Evaluation of the Frictional Resistance between Stainless Steel, TMA and Low Friction TMA Orthodontic Archwires – An In-Vitro Study

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Research Article

Abstract: **Aim:** To understand the frictional forces between the orthodontic brackets and orthodontic wires and to evaluate the frictional resistance of different orthodontic wires. **Materials and method:** The test was divided into six groups comprising of fifteen samples each. Group I - stainless steel wires, Group II - TMA wires, Group III- low friction TMA wires, Group IV - colored low friction TMA wires aqua, Group V - colored low friction TMA wires purple, Group VI - colored low friction TMA wires honey dew. The measurements of friction between bracket and arch wire were done with the Instron Universal testing machine (model no.4701). The results were subjected to statistical analysis. **Results:** On analyzing the mean values of Groups I to VI it was clearly evident that the Group II (TMA) has the maximum frictional resistance and Group VI (colored low friction TMA - honey dew) has the lowest frictional resistance. **Conclusion:** The frictional resistance is highest in TMA, The frictional resistance is lowest in colored low friction TMA honeydew, and the frictional resistance of colored low friction TMA aqua is similar to that of stainless steel.

Keywords: Friction, Stainless Steel Wire, TMA Wire, Low Friction TMA Wire.

Introduction

Straight Wire appliance was the first orthodontic mechanism to be based upon sliding mechanics. The advantage of this system in controlling the positions of the teeth throughout the treatment made it the most popular appliance. The translation technique provides good rotational control but may delay tooth movement and increases anchorage requirements due to the friction generated. Hence it is essential to understand the frictional forces between the brackets and wires in order to produce effective tooth movement within the range of optimal biological response. Friction is defined [1] as a force that retards or resists the relative motion of two objects in contact, and its direction is tangential to the common boundary of the two surfaces in contact. In physics, the frictional force between any two sliding surfaces is directly proportional to the force with which the surfaces are pressed together - $F_{fr} = \mu \times F$. The value of μ (the coefficient of friction) depends on the materials that are sliding and is only very slightly affected by other factors, such as speed or contact areas between the surfaces. Friction is of two types namely static and kinetic friction. Static friction is the smallest force needed to start the motion of solid surfaces that were previously at rest with respect to each other. On the other hand kinetic friction is the force that resists the sliding motion of one solid object over another at a constant speed. In orthodontics, a tooth undergoing a sliding movement along an archwire goes through many tipping and uprighting cycles, moving in small increments. Therefore, orthodontic space closure depends more on static friction than on kinetic friction. Frictional force operates in the opposite direction to the mobile body, it is important that frictional forces should be eliminated or minimized when orthodontic tooth movement is being planned. Mesiodistal tooth movement can be accomplished by free bodily movement or by guidance of a tooth along an arch wire. The major advantage of the former mechanism (e.g., sectional retraction arch wire) is the lack of frictional forces between bracket and arch wire. Unfortunately, such a mechanism is associated with undesired tooth rotations in the sagittal and transverse planes, resulting in an increase in the leveling requirements[2]. By contrast, the latter technique of guiding a tooth along an arch wire decreases adverse rotating movements but leads to friction, which results in a delay in tooth movement, an increase in anchorage requirements, or both[2].

During the past decade, there has been a remarkable increase in the physical properties of the wires available to orthodontists. With the development of chromium-cobalt, nickel-titanium, and titanium-molybdenum alloys, and the production of round and rectangular multibraided wires by several different methods of wrapping 3, 5, 6, 8, or 9 strands of stainless steel, the orthodontist is presented with a wide variety of options. It is often quite difficult to gain clinical experience with the possible applications of so many different wires, and clinical judgments of the "feel" of a wire can be particularly misleading with wires that have variable relationships among the basic physical properties of strength, stiffness, and range. Goldberg and Burstone[3] demonstrated that, with the proper processing of 11% Molybdenum, 6% Zirconium, and 4% Tin, it was possible to develop an orthodontic wire the beta titanium alloy, with a modulus of elasticity, and yield strength superior to that of stainless steel. Laboratory studies[4,5,6] indicate that TMA wires have higher coefficients of friction and produce significantly greater frictional resistance to sliding through orthodontic brackets than stainless steel. Under laboratory conditions, the surface of the titanium wire can become cold-welded to stainless steel brackets, making sliding closure of even small spaces difficult. Hence many procedures were employed to reduce friction of which the ion- implantation process is popular. Ion implantation is a process by which various elements or compounds are ionized and then accelerated towards a target[7]. Ion implantation takes place in a vacuum chamber, where a vapour flux of ions is generated with an electron beam evaporator and deposited on the substrate. Gas ions (nitrogen and oxygen) are simultaneously extracted from plasma and accelerated in the growing physical vapor deposition film at energies of several hundred to several thousand electron volts. The ions penetrate the surface of the wire on impact, building up a structure that consists of both the original wire and a layer of tin compounds on the surface and immediate subsurface. This layer is extremely hard and creates a considerable amount of compressive forces in the material at the atomic level. The compressive forces and increased surface hardness improve the fatigue resistance and ductility and reduce the coefficient of friction of the wire. The superficial compressive forces also minimize any detrimental effects of surface flaws[7]. Unlike conventional coating processes, ion implantation produces no sharp interface between the coating and wire, which can lead to bond failure or delamination. Also unlike coatings, ion implantation does not alter wire dimensions; thus, it allows the production of high-quality wires with close dimensional tolerances. Varying the ion dosage and energy, can control the depth, distribution, and concentration profile. Since ion implantation can take place at relatively low temperatures from subzero to 700°C, it allows improvement of surface characteristics without degradation of other mechanical properties. The thickness of the implanted surface layer can be precisely controlled and its properties engineered to affect characteristics such as hardness, friction, wear resistance, ductility, and fatigue resistance. Varying the type and thickness of ions two varieties of TMA: low-friction and colored TMA were produced. Low-friction TMA has a light golden hue, and the different wire colors are aqua, purple, and honey dew.

Aims and Objectives

The purpose of the present was to evaluate and compare the frictional resistance of Stainless Steel, TMA, Low Friction TMA, Colored Low Friction TMA Aqua, Colored Low Friction TMA Purple and Colored Low Friction TMA Honey Dew.

Materials and Method

The present study was conducted in the Department of Dentistry, Chennai Medical college Hospital and Research centre, along with the collaboration of Central Leather Research Institute (CLRI), Chennai.

Materials used in the study (Fig. 1, 2)

1. 0.016” x 0.022” Stainless steel (ORMCO, California, U.S.A)
2. 0.016” x 0.022” TMA (ORMCO, California, U.S.A)
3. 0.016” x 0.022” Low Friction TMA (ORMCO, California, U.S.A)
4. 0.016” x 0.022” Colored Low friction TMA AQUA (ORMCO, California, U.S.A)
5. 0.016” x 0.022” Colored Low friction TMA PURPLE (ORMCO, California, U.S.A)
6. 0.016” x 0.022” Colored Low friction TMA HONEY DEW (ORMCO, California, U.S.A)
7. Cuspid brackets Roth prescription 90 nos (3M UNITEK, Monrovia, U.S.A)
8. Stainless steel ligatures 0.10” (Ortho Organizers)
9. Pharmacological weight 150 gms
10. Instron universal testing machine (Model no. 4701) (Fig. 3)

Figure 1: Materials used in the study

Figure 2: Colored TMA wires

In this study Tidy's[6] frictional test design was used to simulate canine retraction. The test was conducted under dry condition. The forces acting on the surface of the tooth root were simulated by single equivalent force acting at the center of resistance of the root. The couple produced by the two-point contact with the arch wire counters the moment of this force about the arch wire. The measurements of friction between bracket and arch wire were done with the Instron Universal testing machine. It consisted of a simulated fixed appliance with the arch wire in a vertical position. A special jig (Fig. 1) was constructed to which four premolar brackets (Roth prescription, 0.018" slot stainless steel) was fixed at an interval of 8 mm. A 16 mm open space was left at the center for moving a canine bracket. Another jig with a 21-gauge wire, which was shaped in the form of a "U" to retract the canine bracket, was also fabricated. To simulate the force to act at the center of resistance of the canine, power arms of 10mm length were fixed to the base of the canine brackets. The lengths of the power arms were chosen based on the findings of Burstone[8]. Only straight length portion of the preformed wires were used for the study. 0.010" stainless steel ligatures were used to ligate the canine brackets to the arch wire. The ligatures were tightened first and then opened three turns to permit free sliding of the canine bracket[6]. The jig with the brackets and wire assembly was mounted on the lower jaw of the Instron. The other jig was mounted on to the upper jaw of the Instron. The wire suspended from the upper jig was made to be in contact beneath the canine bracket below the wire (Fig. 4). The crosshead speed was set to move upwards at a speed of 5mm/min. A constant weight of 150 grams[9] was suspended from the power arms to simulate single load acting at the center of resistance of the canine.

In this setup the canine brackets were moved along the arch wire. In each test the brackets were moved a distance of not less than 2.5mm across the central space and the load cell reading were recorded on a digital display.

The test was divided into six groups comprising of fifteen samples each

Group I - Stainless steel wires
Group II - TMA wires
Group III - Low friction TMA wires
Group IV - Coloured low friction TMA wires aqua
Group V - Coloured low friction TMA wires purple
Group VI - Coloured low friction TMA wires honey dew

The load cell readings represented the clinical force of retraction that was to be applied to the tooth, part of which was lost due to friction, while the remainder was transmitted to the root. The difference between the load cell reading and the load on the power arm represented the frictional force decay. The results were subjected to statistical analysis. Mean and standard deviation were estimated from the samples of each group. The values of each group were compared by one-way ANOVA appropriately. Student's independent "t" test was used to compare between the groups and Pearson's test was used to find the correlation between the groups.

Figure 3: Instron Universal Testing Machine – 470

Figure 4: Jigs in Position

Results

The results obtained were subjected to statistical analysis. The mean, standard deviation, error were calculated and tabulated (Table I), and represented graphically (Graph I). Further statistical analysis using one way-ANOVA (Table II), Students independent "t" test (Table III), and Pearson correlation (Table IV) was analyzed.

Table 1: Descriptive Statistics

Group	Mean (gm)	Range (gm)	Standard Deviation	Standard Error
I	176.19	173.24 – 178.95	1.53	0.40
II	457.92	453.84 – 461.25	2.28	0.59
III	235.13	230.54 – 238.24	2.38	0.61
IV	171.53	168.51 – 174.29	1.95	0.50
V	150.62	148.54 – 152.94	1.42	0.37
VI	110.53	108.24 – 112.84	1.33	0.34

Inference

On analyzing the mean values of Groups I to VI it was clearly evident that the Group II (TMA) has the maximum frictional resistance and Group VI (COLOURED LOW FRICTION TMA - HONEY DEW) has the lowest frictional resistance. The mean values have been graphically represented in Graph I.

Table 2: One- way ANOVA

	Sum of Squares	Df	Mean Squares	F	Sig
Between Groups	1167678.5	5	233535.69	67562.97	.000
Within Groups	290.35	84	3.45		.000
Total	1167968.8	89			.000

Inference

Statistical analysis with one-way ANOVA test showed that the values were statistically significant, at a level of significance taken at $p \leq 0.01$.

Table 3: Students independent "t" Test

Groups	t-test for Equality of Means		
	T	Df	Sig(2-tailed)
I	397.42	28	.000
II	397.42	24.5	.000
I	80.77	28	.000
III	80.77	23.92	.000
I	7.29	28	.000
IV	7.29	26.51	.000
I	47.47	28	.000
V	47.47	27.83	.000
I	125.59	28	.000
VI	125.59	27.43	.000
II	262.14	28	.000
III	262.14	27.95	.000
II	369.91	28	.000
IV	369.91	27.34	.000
II	443.57	28	.000
V	443.57	23.41	.000
II	510.43	28	.000
VI	510.43	22.49	.000
III	80.18	28	.000
IV	80.18	26.93	.000
III	118.35	28	.000
V	118.35	22.84	.000
III	177.45	28	.000
VI	177.45	21.94	.000
IV	33.60	28	.000
V	33.60	25.56	.000
IV	100.24	28	.000
VI	100.24	24.66	.000
V	80.06	28	.000
VI	80.06	27.87	.000

Inference

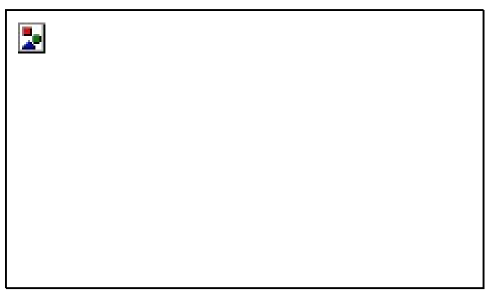
The mean values of all the groups were subjected to the student "t" test and it was found that there was a significant difference between all the groups with the $p < 0.01$

Table 4: Pearson Correlation

Data	GRI	GRII	GRIII	GRIV	GRV	GRVI
GRI Pearson correlation	1.000	.190	.159	.277	.681*	.021
Sig (2 tailed)		.497	.572	.318	.005	.940
N	15	15	15	15	15	15
GRII Pearson correlation	.190	1.000	.080	.092	.106	.400
Sig (2 tailed)	.497		.776	.743	.708	.140
N	15	15	15	15	15	15
GRIII Pearson correlation	.159	.080	1.000	.097	.249	.015
Sig (2 tailed)	.572	.776		.730	.372	.958
N	15	15	15	15	15	15
GRIV Pearson correlation	.277	.092	.097	1.000	.082	.402
Sig (2 tailed)	.318	.743	.730		.772	.137
N	15	15	15	15	15	15
GRV Pearson correlation	.681*	.106	.249	.082	1.000	.152
Sig (2 tailed)	.005	.708	.372	.772		.589
N	15	15	15	15	15	15
GRVI Pearson correlation	.021	.400	.015	.402	.152	1.000
Sig (2 tailed)	.940	.140	.958	.137	.589	
N	15	15	15	15	15	15

Inference

The Pearson's Correlation was used to check the relationship between the groups. This test suggests that there is a significant relationship between Group I (Stainless steel) and Group V (Colored low friction TMA – Purple).



***Graph I*:** Graphical representation of mean values of Group I-VI

Discussion

Orthodontic tooth movement is either carried out through sliding mechanics that involve friction or by mechanics that do not involve friction, or by a combination. Because there is an optimum range of forces for movement of teeth, knowledge of friction is essential to the clinician who uses sliding mechanics. Friction can then be compensated for in the applied force to achieve the net effective force within the range of optimal forces. After initial leveling and aligning, the arch wire is parallel to the bracket slot. As a tooth is translated with sliding mechanics, the crown moves before the root apex does. This results in some tooth tipping and angulation occurring between the bracket and the arch wire. This angulation, in turn, significantly contributes to the overall friction between arch wire and bracket. Eventually, this friction or binding becomes so great that crown movement stops; the couple created by the bracket/wire interaction works to upright the root[1]. This study sought to simulate the clinical situation in which some tooth tipping occurs during translation along an arch wire, since the center of resistance is located on the root and not at the level of the bracket.

Guiding a tooth along an arch wire can be divided in four consecutive phases; [2]

Phase 1. Before application of force in the mesiodistal direction and on completion of the leveling stage, the arch wire lies in the slot, with no conflict.

Phase 2. Concomitant with force application in the mesiodistal direction, the tooth tips and rotates since the point of force application lies above the center of resistance.

Phase 3. Continuous force application sets an elastic deformity in the arch wire. The load at the contact points between wire and bracket increases as well as the friction. Thus a portion of the mesiodistal force is lost. This elastic deformity concurrently produces antitip and antirotational movements of the tooth.

Phase 4. In an unbalanced situation, a permanent deformity of the arch wire can be developed. Obviously, the latter situation should be avoided.

Arch-guided tooth movement consists of repeated movements of tipping and uprighting (phases 1 to 3). In clinical situations, however, additional factors might be involved; for example, masticatory impediment can break this cycle by causing a permanent set in the wire (phase 4). It has been suggested that saliva may reduce friction by acting as a lubricant film. However, a preliminary study has shown no difference between dry models and wet models. This supports the findings of Andreasen et al[10] and Riley et al[11]. Hence the present study was aimed at evaluating the frictional resistance between an 0.016" x 0.022" Stainless Steel, TMA, low friction TMA and colored TMA archwires and an 0.018" slot canine bracket in a dry state. Rectangular wire was chosen for this study because it offers control in all three planes of space, whereas round wire gives control only in two planes[12, 13]. As with other studies [12, 14] on comparison of the frictional resistance between stainless steel and TMA wires the present study also confirms the comparatively higher frictional resistance of the TMA wires. The ion implanted varieties of the TMA archwires exhibit statistically lower frictional resistance than the untreated TMA archwires, and in some cases (Purple) statistically similar or even lesser (Aqua, Honey Dew) frictional resistance than Stainless steel. Similar studies on ion-implanted TMA showed varied results, Michelberger et al[15] demonstrated an increase in the friction in ion-implanted TMA, while the work by Curtis et al[16] showed a decrease in the fictional resistance of certain ion-implanted TMA's. This difference could be attributed to the difference in the test design employed by the different authors. The reduction in the friction could be attributed to the process of ion-implantation, as it tends to increase stress fatigue, hardness, and wear regardless of the composition of the material. The hardness of a material is generally defined as resistance to scratching or wear[17]. Because the coefficient of friction is inversely proportional to the "hardness," by increasing the hardness of a material the friction is decreased[17]. Perhaps this explains why a reduction in friction was seen in the two different wire types, regardless of the composition. Although TMA wires are usually not considered the wire of choice for closing space because its frictional resistance is high, the computed monthly rate of closing on TMA (0.12 to 2.46 mm/month) is surprisingly similar to the rates of space closing reported on stainless steel wire (0.76 to 1.75 mm/month) [18]. Laboratory studies,[19, 20, 21] have almost uniformly shown that the frictional forces and coefficients of friction for TMA wires are higher than that for other commonly used orthodontic wires such as stainless steel or nickel-titanium; this suggests that TMA wires would not allow efficient sliding. On the other hand a clinical study by Kula et al[18] showed no difference in the retraction of the canines between either TMA or ion-implanted TMA. This could be explained by the fact that in a clinical situation, masticatory function may enhance sliding by providing the forces to flex the archwires and break the cold-welds that appear to be significant factors in frictional resistance in the laboratory. The relative lack of masticatory forces in the incisor region as compared with the posterior dental segments could explain failure of small anterior spaces to close. Thus, TMA wires especially the colored low friction TMA (Honey dew) may be considered as an alternative choice for closing extraction spaces. Over the years, numerous investigators have indicated that applying the proper magnitude of force during orthodontic treatment will result in optimal tissue response and rapid tooth movement. Schwartz[22] proposed that orthodontic force should not exceed capillary blood pressure in the periodontal ligament. Storey and Smith [23] developed the concept of optimal force required for maximum rate of tooth movement. Other relationships between orthodontic force and tooth movement have been proposed, and a critical review of some of these hypotheses has been provided by Quinn and Yoshikawa[24]. These authors conclude that the rate of tooth movement increases with increases in applied force up to a point, after which additional force produces no appreciable increase in tooth movement. During mechanotherapy that involves movement of a bracket relative to a wire, friction at the bracket-wire interface may prevent the attainment of optimal force in the supporting tissues. Hence, orthodontists need to know more precisely what level of force is required to overcome this friction and produce the optimal biologic response for predictable tooth movement. Several variables have been implicated by previous investigators, as affecting friction at the bracket-wire interface. All but one of these investigations used stainless steel brackets to study the effects of such variables as wire alloy, [25] wire size, [25] bracket width, [25] ligature material and tying force,[26] and salivary lubrication[27] on frictional force. But with the advent of ceramic brackets and their increasing popularity indicate a need for understanding the force required to overcome friction when these brackets are used. As with any in vitro study, this investigation does not replicate what actually occurs intraorally during tooth movement. This study provides a means by which to compare different wires under similar testing conditions. Some principles and conclusions can be drawn from the results, but one must be careful about applying this information to clinical situations.

Conclusion

The introduction of the concept of ion implantation into the field of orthodontics has warranted this in-vitro study which was conceived to determine the frictional resistance of the low friction TMA arch wires. Tidy's frictional test design was used to determine the frictional resistance of commercially available stainless steel, TMA and ion-implanted TMA archwires simulating a canine retraction procedure. An Instron universal testing machine was used. The canine bracket was moved along the arch wire for a distance of about 2.5 mm on a specially constructed jig. The load cell reading represented the amount of force required to retract the canine. From the load cell readings the load on the power arm (150 gms) was deducted and this value represented the loss of force due to friction. The results were then subjected to statistical analysis.

The results of the study indicates:

1. The frictional resistance is highest in TMA
2. The frictional resistance is lowest in coloured low friction TMA honeydew,
3. The frictional resistance of coloured low friction TMA aqua is similar to that of stainless steel.
4. The presence of oxides on the surface as result of ion implantation could have increased the surface hardness of the material which would have led to the reduction in the frictional resistance of the coloured low friction TMA arch wires.

The pre adjusted edgewise appliance has always been popular because it is easy to work and also provides good control of the tooth during the process of retraction. But friction has always been a trouble to this appliance system, and hence there was always a need to reduce it. The process of ion implantation has added the low friction TMA and the coloured low friction TMA wires to the orthodontic armamentarium. These wires certainly reduce friction in the process of retraction thereby reducing treatment time and anchorage requirements. The only disadvantage of the colored low friction TMA arch wires, in spite of having a lower frictional resistance than stainless steel are its cost. Due to the number of variables like number of samples tested, technique employed and the difference between in vivo and in vitro conditions etc., it is suggested to have further clinical studies before incorporating these wires into the orthodontic armamentarium.

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Appendix

SS	TMA	LFTMA	AQUA	PURPLE	HONEY DEW
173.24	460.29	238.24	173.84	150.31	110.53
178.95	456.96	234.81	168.51	152.94	109.26
174.84	459.94	234.24	170.53	148.61	108.24
175.29	454.61	237.29	171.52	148.54	110.82
177.64	458.21	236.79	172.26	151.97	111.61
178.31	459.27	235.76	174.29	152.42	112.84
176.44	458.94	238.16	170.84	152.34	110.99
174.54	461.25	230.54	172.92	149.62	112.45
176.49	453.84	231.49	172.91	150.86	109.43
176.34	456.47	235.42	173.83	150.75	109.52
176.82	457.51	236.72	171.59	151.77	110.61
174.62	457.29	231.42	172.67	149.83	110.94
177.28	458.35	235.86	169.46	149.89	108.93
175.66	454.94	234.83	168.53	150.49	109.84
176.43	460.87	235.43	169.21	148.99	111.87