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Effect of oral environment and prescribed fluoride mouthwashes on different types of TMA wires – An *in-vivo* study

Arun Rajendran, Shobha Sundareswaran, Latheef Vadakke Peediyekkal, Praveen Santhakumar and Sreehari Sathyanadhan

Abstract:

OBJECTIVE: The aim of this study was to investigate the effect of intraoral conditions and fluoride mouthwashes on mechanical properties and surface characteristics of different types of titanium molybdenum alloy (TMA) wires.

MATERIALS AND METHODS: Three types of TMA wires of dimension 0.017" × 0.025" [1. Standard TMA (TMA), 2. ion-implanted, low-friction TMA (LF) and 3. Colored, Honey Dew TMA (HD)] were tested in three conditions as three groups; A) Control (as received), B) No fluoride (following intraoral use without fluoride) and C) Fluoride (following intraoral use with fluoride rinses). Surface roughness was evaluated using 3D Optical Profilometer. Three point bending tests were done to evaluate load deflection characteristics (LDR), ultimate tensile strength (UTS), and Young's modulus (E). Statistical evaluation was done using one-way analysis of variance (ANOVA), Bonferroni multiple comparison, and paired *t*-tests.

RESULTS: Control group TMA exhibited significantly higher surface roughness, peak height, and LDR as well as lower UTS and E when compared to LF and HD ($P < 0.001$). In nonfluoride group, the surface roughness and LDR increased significantly for all three types of wires ($P < 0.001$). The UTS and E showed a significant decrease ($P < 0.001$). Additional use of fluoride mouthwashes (fluoride group) further increased surface roughness and LDR and decreased the UTS and E ($P < 0.001$).

CONCLUSION: The ion-implanted LF/HD varieties had better surface smoothness, lower LDR, higher UTS, and higher E than standard TMA in the control group, pointing towards a better efficiency of these wires. Intraoral conditions significantly increased surface roughness and deteriorated mechanical properties of all types of TMA wires. With the use of daily fluoride mouthwashes, the deterioration was much worse.

Keywords:

Beta-titanium, fluorides, ion implanted titanium molybdenum alloy, oral environment, wire properties

Department of
Orthodontics and
Dentofacial Orthopedics,
Government Dental
College, Calicut, Kerala,
India

Address for correspondence:

Dr. Shobha
Sundareswaran,
Department of
Orthodontics and
Dentofacial Orthopedics,
Government
Dental College,
Calicut - 673 008, Kerala,
India.
E-mail: drshobhakumar@
gmail.com

Introduction

The titanium molybdenum alloy (TMA) archwires were introduced into orthodontics in 1979 by Goldberg and Burstone.^[1] Due to its biocompatibility, low stiffness, and resistance to corrosion, these archwires have gained popularity in

making loops, springs, and intrusion arches. Providing light continuous forces with large amount of activation for long periods helps to lengthen clinical appointment intervals and may shorten total treatment period.^[2]

However, one disadvantage is that these TMA wires have been shown to develop frictional forces five times greater than that of stainless steel.^[3] The mean coefficient of

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friction in dry state is said to be the highest for TMA, and in wet state, it decreases to 50%.^[4] It is said that if 100 g net force is needed for tooth movement, another 100 g will be needed for overcoming the effects of binding and friction.^[5] Hence, many procedures have been employed to reduce friction, of which the ion-implantation process is popular.^[6] It reduces surface flaws and coefficient of friction of the wire and increases surface hardness, compressive forces, and fatigue resistance without altering wire dimensions. As implantation takes place at relatively low temperatures, the mechanical properties of the wire will not be degraded.^[7] By precisely varying the size and type of ions, two types of TMA are produced: (1) Low-friction, ion-implanted TMA and (2) Colored low-friction TMA, available in colors aqua, purple, violet, and honey dew.^[6] Laboratory studies on colored TMA wires have shown that honey dew has the least surface roughness with aqua, purple, and violet producing frictional resistance values similar to standard TMA.^[7-9]

Mechanical properties and surface characteristics of wires can be influenced by a variety of conditions in the oral cavity.^[10] Good oral hygiene with no posttreatment white spot lesions on enamel is an important component of successful orthodontic treatment. To address this issue, many orthodontists prescribe daily fluoride mouthwashes. Titanium-based alloys are said to have high corrosive resistance due to passivation, i.e., formation of a thin stable oxide layer.^[11] However, fluoride prophylactic agents reportedly cause corrosion and discolorations of titanium-based orthodontic wires.^[12]

There are several studies on TMA wires, majority of which have been done in the laboratory using artificial saliva to simulate oral conditions.^[11,13] However, it has been recognized that the storage media used in *in-vitro* studies consist of electrolytes and acidic solutions, which cannot reliably simulate the oral environment.^[10] To counter this problem, *in-vivo* studies are necessary to understand the actual effect of salivary pH, food habits, and fluoride prophylactic agents on the surface characteristics and mechanical properties of wires. Changes in surface characteristics and coating stability of aesthetic NiTi wire have been reported after comparative evaluation with conventional stainless steel and NiTi following 21 days of intraoral exposure.^[12] An *in-situ* investigation by Abbassy *et al.* on TMA wires has reported that application of topical fluoride caused deterioration of its surface properties.^[14] There are no other *in-vivo* studies till date evaluating the mechanical properties of TMA wires after intraoral use with/without fluoride prophylactic agents. This study intends to address this lacuna.

The aim of this study was to investigate the effect of intraoral conditions and fluoride prophylactic agents on mechanical properties and surface characteristics

of different types of TMA wires. The null hypothesis generated was that there may be no change in surface characteristics and mechanical properties of TMA wires with intraoral use and fluoride prophylactic agents.

Materials and Methods

This study was conducted jointly by The Department of Orthodontics, Government Dental College and Department of Chemical and Mechanical Engineering, National Institute of Technology. The study was approved by The Institutional Research Board and The Institutional Ethics Committee (IEC No. 66/2015/DCC). Three types of TMA wires of dimension 0.017" × 0.025" were used; 1. Standard TMA (TMA → GAC, Bohemia New York), 2. Low Friction TMA (LF → ORMCO, Glendora, California), 3. Honey Dew TMA (HD → ORMCO, Glendora, California). Honey Dew (HD) was selected as *in-vitro* studies had reported the wire to have the least surface roughness.^[8] Sample size was calculated using formula $N = (Z\alpha + Z\beta) 2 SD2 \times 2/d2$ based on a previous study.^[15] To detect a difference of 10 to be statistically significant, the sample size was calculated as 16 in each group.

Patients selected included those with Class I bimaxillary protrusion/mild crowding exhibiting moderate to high risk for caries, as assessed by the Salivary Buffer Capacity test (Dentobuff Strip Test).

The tests were conducted in three groups:

1. Control group (as-received wires),
2. No fluoride group (wires retrieved following intraoral use for 4 weeks without fluoride exposure.^[15] Patients were not prescribed any mouthwashes and were also instructed to use nonfluoride containing toothpastes only)
3. Fluoride group (wires retrieved following intraoral use of a prescribed fluoride mouthwash (SENQUEL-AD mouthwash, Dr. Reddy's Laboratory- 0.2% sodium fluoride, 3% potassium Ni, with 904 ppm fluoride content, pH-7). Patients were instructed to use about 10 ml of the mouthwash thrice daily, duration of 3 min per rinse during the 4-week period. Patients were instructed not to eat, drink, or rinse for 30 min after fluoride application.

The patients in our study had their teeth levelled and aligned on a 0.022 × 0.028-inch slot size MBT prescription brackets (3M Unitek, Gemini metal brackets, CA, USA), with 0.017 × 0.025-inch NiTi wires followed by 0.017 × 0.025-inch TMA with no force applied on them to avoid any frictional forces exerted from the brackets.

The used wires were retrieved from patients and rinsed with double distilled water to detach any loose bound precipitation. Straight pieces of adequate length were

cut from the distal end of preformed arch-wires. All the tests were performed at room temperature and wires subjected to multitechnique characterization.

Surface roughness test

The surface roughness was evaluated using a 3D Optical Profilometer (Alicona Infinite Focus 5G, Austria). This is a noncontact method which optically scans the whole surface resulting in a three-dimensional representation. The surface of the 10-mm straight wire was observed on its 0.625 mm side with a 10× lens [Figure 1]. Three different areas on each sample were randomly chosen and mean of the three areas were taken for image evaluation. The Alicona Infinite Focus Measure Suit software was used to quantify the surface morphology by reconstructing a 3D surface, from which mean surface roughness values (Sa and Sz) were calculated, where Sa is the average height of the selected area and Sz is the maximum height of the selected area.

Three-point bending test

The load-deflection characteristics of specimens from each group were evaluated using three-point bending test previously described by Miura *et al.*^[16] A specially designed fixture with two supports 14 mm apart equal to the interbracket distance between upper central incisor and canine was used. The test wire specimens were secured on brackets fixed on the poles using Elastomeric ligatures (ORMCO, Glendora, California). Testing was done using Universal testing machine (Autograph AG-X plus, 10KN, Schimadzu, Singapore). Trapezium X software was used to analyze the results. The cross-head speed for loading was 1 mm/min. The mid portion of the wire was deflected up to 10 mm. For every extension of 1.5 mm, the load was recorded and statistically evaluated [Figure 2]. The load taken to break the wire divided by its cross-sectional area was evaluated for ultimate tensile strength (UTS). The load deflection data obtained from bending test was plotted on a stress-strain

curve from which modulus of elasticity (E) was calculated using Trapezium X software. Statistical evaluation was done using one-way analysis of variance (ANOVA), Bonferroni multiple comparison, and paired z-tests.

Results

Table 1 shows means with standard deviation of surface roughness and mechanical properties of TMA, LF, and HD wires in the Control group. One-way ANOVA

Table 1: Mean and SD of surface characteristics and mechanical properties of TMA, LF and HD in control group (as-received)

Properties	n	Mean	Std. deviation
Sa1			
TMA	16	431.5631	26.6844
LF	16	354.3055	16.7188
HD	16	356.5407	8.8614
Sz1			
TMA	16	6.5087	0.5652
LF	16	5.6664	0.6135
HD	16	5.0596	0.5801
LDR1			
TMA	16	10.0814	0.6258
LF	16	9.3195	0.2217
HD	16	9.2155	0.4608
UTS1			
TMA	16	1325.213	17.354
LF	16	1924.950	51.985
HD	16	1901.043	18.995
E1			
TMA	16	67.40593	5.89354
LF	16	97.12370	1.63742
HD	16	96.95805	0.86681

TMA-standard TMA; LF-Low Friction TMA; HD-Honey Dew TMA; Sa1-average height of selected area in control group; Sz1-maximum height of selected area in control group; LDR1-load deflection rate in control group; UTS1-ultimate tensile strength in control group; E1-Young's modulus in control group; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

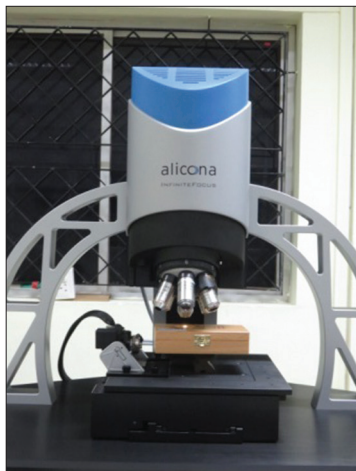


Figure 1: Optical Profilometer (ALICONA 3D) with sample in position

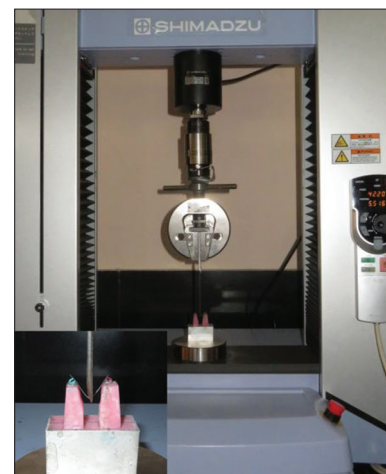


Figure 2: Universal Testing Machine (AUTOGRAPH AG-X plus, SCHIMADZU) with load deflection apparatus and the specimen under load

revealed highly significant ($P < 0.001$) differences in all properties [Table 2]. Results of the Bonferroni multiple comparison [Table 3] showed that the differences in surface roughness, peak height, load deflection rate, ultimate tensile strength, and Young's modulus were highly significant ($P < 0.001$). However, there were no significant differences between LF and HD. Table 4 gives the mean values of surface roughness and peak height

of TMA, LF, and HD wires in all three groups. A highly significant increase in value for surface roughness and peak height ($P < 0.001$) was observed for all three types of wires in the "No fluoride" group. Following the additional use of daily fluoride mouthwashes, the surface roughness and peak height values increased still further, and the difference was found to be statistically highly significant ($P < 0.001$). Changes in surface roughness of TMA, LF, and HD in all three groups are given in Figures 3-5.

Table 2: One way ANOVA analysis of Surface characteristics and Mechanical properties between groups

Properties	Comparison	F	Sig.
Sa1	Between Groups	91.199	0.000
Sz1	Between Groups	24.621	0.000
LDR1	Between Groups	16.426	0.000
UTS1	Between Groups	1644.921	0.000
E1	Between Groups	368.178	0.000

Sa1-average height of selected area in control group; Sz1-maximum height of selected area in control group; LDR1-load deflection rate in control group; UTS1-ultimate tensile strength in control group; E1-Young's modulus in control group; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 3: Bonferroni test showing the significance between TMA, LF and HD for each property in control group

Dependent variable	I sample	J sample	Sig.
Sa1	TMA	LF	0.000
	HD		0.000
	LF	HD	1.000
Sz1	TMA	LF	0.001
	HD		0.000
	LF	HD	0.016
LDR1	TMA	LF	0.000
	HD		0.000
	LF	HD	1.000
UTS1	TMA	LF	0.000
	HD		0.000
	LF	HD	0.148
E1	TMA	LF	0.000
	HD		0.000
	LF	HD	1.000

TMA-standard TMA; LF-Low Friction TMA; HD-Honey Dew TMA; Sa1-average height of selected area in control group; Sz1-maximum height of selected area in control group; LDR1-load deflection rate in control group; UTS1-ultimate tensile strength in control group; E1- modulus of elasticity in control group; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

A similar highly significant increase in load deflection rate ($P < 0.001$) was observed for all three types of wires in no fluoride group [Table 5]. This was found to increase still further in fluoride group ($P < 0.001$). Both UTS and Young's modulus of TMA, LF, and HD showed a significant decrease in no fluoride group ($P < 0.001$). A further significant drop was observed in fluoride group ($P < 0.001$; Tables 6 and 7).

Discussion

Comparison of wires in control group

The surface roughness of the wire was evaluated using an optical profilometer in this study. The distinct advantage of this instrument is that it is a noncontact method using optical scans for 3D representations making it more reliable than surface profilometer/SEM evaluation.

Optical profilometer findings in control group show that surface roughness of TMA is significantly higher than that of LF and HD, which is in concurrence with previous results.^[6,17,18] Because those studies had used different evaluation methods, quantitative comparison of the surface deterioration of our study with theirs was not possible. This is in contradiction to the findings of Kusy who concluded that the surface roughness cannot be drastically reduced by ion implantation.^[19] The present study observed that there was no significant difference in surface roughness values between LF and HD. This result does not support previous findings reporting HD to be the smoothest of all ion-implanted types.^[7,8,20]

Table 4: Mean values and Standard Deviations of surface roughness of TMA, LF, and HD in different groups

Group	Sa1		Sa2		Sa3		Sa1-Sa2		Sa2-Sa3	
	Sz1		Sz2		Sz3		Sz1-Sz2		Sz2-Sz3	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
TMA	431.5631	25.6844	497.1637	60.3232	642.6010	56.1356	-65.6003**	73.152	-145.437***	86.6941
	6.5087	0.5652	7.6967	1.0667	9.4388	1.3240	-1.1879***	0.8526	-1.7420***	1.2855
LF	354.3055	16.7188	376.8567	17.1826	450.9977	53.6010	-22.5512***	9.9795	-74.1410***	59.2612
	5.6664	0.6135	6.5628	0.9957	7.8270	1.0574	-0.8964***	0.5964	-1.2642***	0.7080
HD	356.5407	8.8614	384.4601	26.1186	410.0385	38.2088	-27.9194***	28.4784	-25.5783***	25.7089
	5.0596	0.5801	6.3053	0.5943	7.2347	0.2304	-1.2457***	0.7791	-0.9293***	0.6940

TMA-standard TMA; LF-Low Friction TMA; HD-Honey Dew TMA; Sa1-average height of selected area in control group; Sa2-average height of selected area in Non fluoride group; Sa3-average height of selected area in Fluoride group; Sz1-maximum height of selected area in control group; Sz2-maximum height of selected area in Non fluoride group; Sz3-maximum height of selected area in Fluoride group; SD- Standard Deviation; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

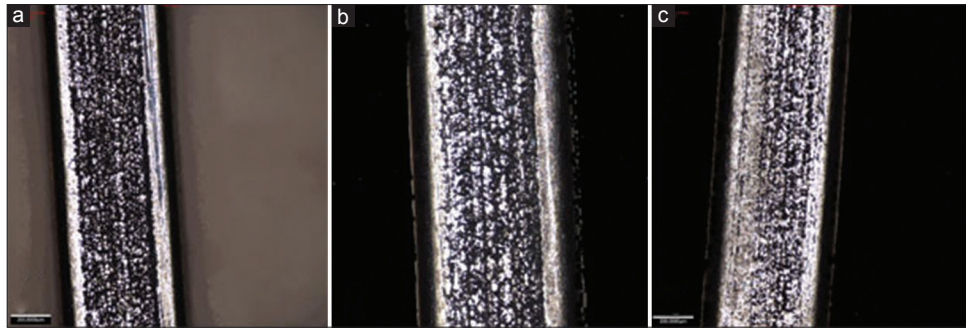


Figure 3: Standard TMA in three groups. a → TMA1- control group, b → TMA2- Nonfluoride group, c → TMA3- fluoride group

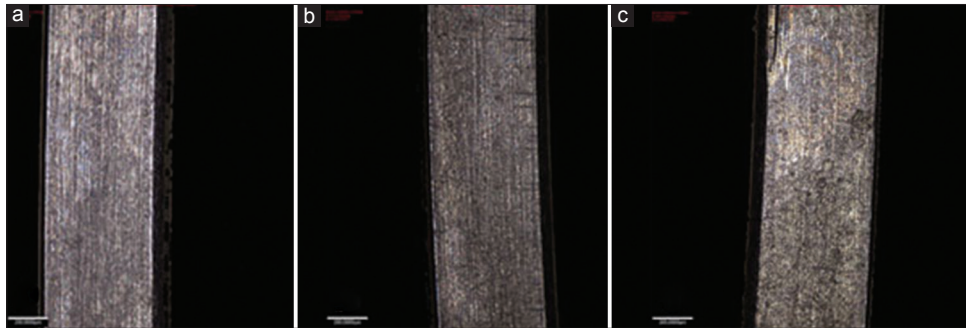


Figure 4: Low Friction TMA (LF) in three groups. a → LF1- control group, b → LF2- Nonfluoride group, c → LF3- fluoride group

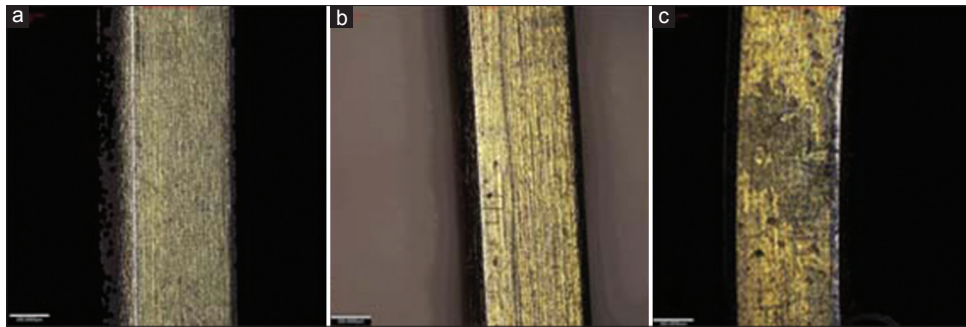


Figure 5: Honey Dew TMA (HD) in three groups. a → HD1- control group, b → HD2- Nonfluoride group, c → HD3- fluoride group

Table 5: Mean values and Standard Deviations of Load Deflection Rate TMA, LF, and HD in different groups

Group	LDR1		LDR2		LDR3		LDR1-LDR2		LDR2-LDR3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TMA	10.0814	0.6258	12.1704	0.6520	12.4068	0.467	-2.0890***	1.0636	-0.2363	0.7713
LF	9.3194	0.2217	12.8452	0.6696	13.5042	0.8344	-3.5257***	0.6436	-0.6589**	0.7424
HD	7.9792	0.32222	12.6810	1.0067	13.3541	0.9003	-3.4654***	1.1269	-0.6731**	0.9927

TMA-standard TMA; LF-Low Friction TMA; HD-Honey Dew TMA; ; LDR1-load deflection rate in control group; LDR2-load deflection rate in Non fluoride group; LDR3-load deflection rate in fluoride group; SD-Standard Deviation; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 6: Mean values and Standard Deviations of Ultimate Tensile Strength (UTS) of TMA, LF, and HD in different groups

Group	UTS1		UTS2		UTS3		UTS1-UTS2		UTS2-UTS3	
	mean	SD	Mean	SD	Mean	SD	mean	SD	mean	SD
TMA	1325.23	17.35	1099.88	127.21	882.87	108.49	225.34***	134.78	217.00***	165.98
LF	1924.95	51.98	1522.05	75.14	1404.30	62.71	402.89***	84.67	117.75***	62.59
HD	1901.04	18.99	1492.72	90.71	1345.27	75.55	408.32***	91.58	147.44***	65.24

TMA-standard TMA; LF-Low Friction TMA; HD-Honey Dew TMA; UTS1-ultimate tensile strength in control group; UTS2-ultimate tensile strength in Non fluoride group; UTS3-ultimate tensile strength in fluoride group; SD- Standard Deviation * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 7: Mean values and standard deviations of modulus of elasticity (E) of TMA, LF, and HD in different groups

Group	E1		E2		E3		E1-E2		E2-E3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TMA	67.4059	5.8935	51.4405	6.9141	42.5313	5.1297	15.9653***	7.8305	8.9092***	8.3407
LF	97.1237	1.6374	92.3047	3.6116	85.3695	5.8364	4.8189***	4.1543	6.9351***	5.37372
HD	96.9580	0.8668	92.9822	1.5378	85.7473	2.9309	3.9757***	1.4740	7.2493***	3.15842

TMA-standard TMA; LF-Low Friction TMA; HD-Honey Dew TMA; E1-Young's modulus in control group; E2-Young's modulus in Non fluoride group; E3-modulus of elasticity in fluoride group; SD- Standard Deviation, * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Three-point deflection test done in the Control group showed that LDR (force required to deflect the wire to a depth of 1.5 mm) was significantly higher for standard TMA compared to the ion-implanted varieties. This is in line with previous findings.^[9,17] The lower load deflection properties of the colored TMA wires might be due to the etching and heating process, while coating is performed over archwire blanks.^[9] There were no significant differences between HD and LF. The lower LDR may permit the usage of ion-implanted TMA in patients with periodontally compromised conditions.

Mechanical properties such as UTS and E of all the three groups of wires in Control group showed that these values for LF and HD are significantly higher than that of TMA. This result is in contradiction to the findings of Burstone *et al.*, who observed no significant change in the mechanical properties of ion-implanted TMA when compared to standard TMA.^[6] The stated reason for this is that implantation takes place at relatively low temperatures. Thus, the ion-implanted TMA varieties had better surface smoothness, lower LDR, higher UTS, and E than standard TMA, pointing towards a better efficiency of these wires than normal TMA. No statistically significant difference was seen between LF and HD for UTS and E.

Effect of oral environment and fluoride mouthwashes

Most of the previous investigations on the effect of oral environment and fluoride on the surface characteristics and mechanical properties of TMA wires have all been *in-vitro* studies following immersion in artificial saliva/fluoride solutions.^[19,20] This need not necessarily simulate the actual intraoral environment, where the pH of the saliva can range from 5.6 to 6.7 depending upon dietary habits, diseases, and internal stimuli such as vomiting.^[15] Effect of fluoride ions on surface properties of TMA wires have been reported in an *in-situ* study by Abbassy *et al.*^[14] To understand more about the influence of oral environment, the present study focused on retrieved TMA wires following real-time intraoral use for 4 weeks with and without prescribed fluoride mouthwashes.

An important finding in the present study is the significant increase in surface roughness and deterioration of all

mechanical properties in the oral environment, which become more pronounced after usage of daily fluoride mouth rinses. This result is in concurrence with the *in-vitro* study of Eliades, who stated that orthodontic alloys are in contact with a variety of substances that impose potent effects on their reactive status and surface integrity.^[10] These include

1. Saliva which may contain acids arising from the degradation and decomposition of food
2. Environmental factors including several parameters including air. It has been estimated that an urban mouth-breather inhales in 2 h approximately one cubic meter of air with a potential sulfur dioxide intake of up to 2.3 mg
3. Oral flora and its byproducts. The action of microbial colonization is twofold.

(i) Certain species can take up and metabolize metals from alloys. (ii) Microbial byproducts and the metabolic processes may alter the condition of the microenvironment (i.e., decreasing the pH, thereby contributing to the initiation of corrosion process).

Our observations on the effect of fluoride mouthwashes in different types of TMA wires agree with Walker *et al.*, who reported that fluoride solutions with neutral pH followed the pattern of acidic fluoride solutions in deteriorating the surface roughness under *in-vitro* conditions, producing topographical changes on the surface of TMA by disrupting the protective oxide layer.^[21] Our observations also agree with the result of *in-situ* studies on the effects of fluoride and intraoral environment on TMA and Ni-Ti wires done by Abbassy *et al.*, which has reported the coverage of TMA wires with corrosion products and peeling of surface with numerous deep grooves following fluoride use intraorally, and the effects were same with Ni-Ti wires.^[14,22] These studies did not give a quantitative assessment as they had used SEM for evaluating the surface property. Reports from another *in-vitro* study conducted on commercially pure titanium using neutral fluoride solutions show that fluoride concentration more than 0.1% produced severe corrosion.^[23] The use of different evaluation methods combined with the fact that most of the studies used acidic fluoride solutions made comparisons with previous studies difficult.

The scanned images of TMA, LF, and HD using 10× objective lens with 100 nm vertical resolution of ALICONA 3D optic profilometer are given in Figures 3-5. Figure 3 shows changes in surface roughness of TMA in all three groups. Cracks seen in TMA2 denote the increase in surface roughness. The roughness is more enhanced with cracks and pits in TMA3. Figures 4 and 5 show changes in surface roughness of LF and HD, respectively, in all three groups. Pits visible on the surface of LF2 and HD2 indicate increase in surface roughness following intraoral use. LF3 and HD3 show increased pitting, cracks, and peeling, indicative of further deterioration. It was not possible to compare our findings with previous work, as use of optic profilometer for evaluating surface characteristics of TMA has not been done so far.

It is reported that archwire and slot dimensions have relatively little influence on friction.^[3] According to Kusy *et al.* and the mean coefficient of friction in wet state is reduced by 50% of its value in dry state.^[4] Hence, in our study the effect of friction on surface properties were considered negligible.

Mechanical properties showed a proportionate, highly significant decrease along similar lines for all the three tested groups of wires in both intraoral conditions. A previous *in-vitro* study evaluating changes in E and yield Strength (Y) of normal TMA using fluoride agents at different pH showed a decrease of 3 ± 2.1 GPa in E.^[21] The present study revealed a reduction of 15.96 ± 7.83 GPa in modulus of elasticity in nonfluoride group. A further decrease of 24.87 ± 7.61 GPa was observed when patients used fluoride mouth rinses. LF and HD also demonstrated similar patterns in deterioration of properties, but to a lesser extent than TMA. The paucity of *in-vivo* studies in assessing these properties on the above-mentioned wires makes further comparisons impossible. From the available results and comparisons with previous *in-vitro* studies we may conclude that deterioration of mechanical properties in TMA wires in the oral environment is five times more than simulated *in-vitro* condition. The use of fluoride mouth rinses apparently proved to be more detrimental as the deterioration in mechanical properties was much more than that observed in laboratory conditions following immersion in fluoride solutions. This obviously has important clinical implications.

LDR for the three groups of wires were compared in all three groups. The results showed that all the three types of wires required a significantly higher force to deflect the wire to a distance of 1.5 mm in nonfluoride group when compared to the control group. Following intraoral use with daily prescribed fluoride mouth rinses (fluoride group), the LDR was still higher for

these wires, with statistical significance for LF and HD. As there are no studies in the literature evaluating the mechanical properties of TMA after real time intraoral use, comparisons with other results was not possible.

A possible explanation for this increase in LDR after intraoral use can be attributed to the effect of intraoral conditions. In a corrosive medium (saliva), under repeated cyclic stressing, alloys are reported to become more brittle due to corrosion fatigue.^[10] With the added usage of neutral fluoride mouthwashes, the corrosion of these wires increases.^[22,23] According to Abbassy, the protective titanium oxide film on the surface of the wire undergoes a reaction in fluoride solutions resulting in the formation of titanium fluoride, titanium oxide fluoride, or sodium titanium fluoride on the surface of the alloy. Corrosion resistance decreases markedly and destruction of oxide layer leads to the absorption of hydrogen from various solutions because of the high affinity of titanium to hydrogen called "hydrogen embrittlement."^[23] After immersion of TMA in fluoride solution, the fracture mode is also said to change from ductile to brittle with a decrease in tensile strength.^[24]

Patients using fluoride mouthwashes should be motivated for strict adherence to oral hygiene instructions. Regular check-ups are mandatory, during which time close monitoring for development of new caries lesions has to be performed. Another option is to prescribe fluoride free mouth rinses in less caries prone patients.

Limitation: The effect of these microstructural changes at the atomic level are needed for a complete understanding of mechanical and surface properties of beta titanium alloys, which was beyond the scope of this study. Further investigations are needed for this.

Conclusion

The findings of this study showed:

1. A statistically significant decrease in surface roughness and LDR and increase in UTS and E of standard TMA wires was observed, as compared to the ion-implanted LF and HD varieties in the as-received condition
2. Following intraoral use, a statistically significant increase in surface roughness was observed in all three types of TMA, which was still further increased with the daily use of fluoride prophylactic agents
3. The mechanical properties deteriorated significantly in the three types of wires following intraoral use. Use of daily prescribed fluoride mouthwashes led to further deterioration.

Thus, all the three null hypotheses stands rejected.

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Conflicts of interest

There are no conflicts of interest.

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