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A detailed study to evaluate and compare the change in the modulus of elasticity and yield strength during the loading and unloading phase for five different orthodontic wires as a result of exposure to prophylactic fluoride agents and GC tooth mousse with distilled water using 3 point bend test

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***Abstract*---**Direct bonding and de-bonding procedures during orthodontic treatment lead to areas of enamel demineralization around brackets. During the etching procedures some of the extra area also gets etched and may remain exposed for plaque accumulation resulting in demineralization and white spot lesions around the brackets. To prevent this we use Ortho brush, Chlorhexidine mouth rinses, Fluoride mouth rinses and recently available GC Tooth mousse. However, they may cause corrosion and discoloration of Orthodontic wires1.Mechanical properties of the wire like Yield strength and Modulus of elasticity affects the performance of wire inside the oral cavity. Surface topography of archwire is one of the factors which influence the mechanical properties. Orthodontic mechanotherapy encompasses the use of several arch wires during various stages of treatment. Stainless steel, Nickel titanium and TMA wires are the ones predominately used. In this study we are trying to evaluate and compare the mechanical properties of Nickel titanium, Copper nickel titanium, β Titanium, Stainless steel and Australian 0.016" stainless steel wires immersed in FLUROVIL gel, PHOSFLUR mouth rinse and GC Tooth mousse with those immersed in Distilled water.

***Keywords*---**Demineralization, Yield strength, Modulus of elasticity, Orthodontic, Mechanical properties.

Introduction

Maintaining proper dental hygiene and controlling cavities is one of the most crucial conditions for effective orthodontic treatment. Around orthodontic brackets, regions of enamel demineralization are caused by direct bonding and de-bonding procedures. Oftentimes during these treatments, areas other than those protected by brackets are etched, leaving them open to plaque buildup. Around the brackets, these etched regions cause demineralization and white spot lesions.Orthodontic patients frequently utilise mouthwashes containing fluoride, chlorhexidine, or both, as well as the more newly introduced GC Tooth mousse. Yield strength and modulus of elasticity, two mechanical characteristics of the wire, have an impact on how well it performs inside the mouth cavity.[1,2]The topography of an archwire's surface is one of the elements that affects its mechanical characteristics. Several arch wires are employed at various phases of treatment in orthodontic mechanotherapy. Wires made of stainless steel, nickel titanium, and TMA are most frequently utilised. The surface oxides on titanium and its alloys are readily passivated metals that do not degrade under physiological circumstances.[3,4] Studies have examined the impact of fluoride ions on the mechanical qualities and surface features of titanium- and stainless-steel-based arch wires. It's crucial to preserve the integrity of the enamel surface. Should orthodontic patients be provided preventative fluoride mouthwashes to protect the health of their teeth. The decision to provide fluoride mouthwashes during orthodontic treatment to preserve the health of teeth is fraught with difficulty.

G.C.Tooth mousse has recently gained popularity as a preventative measure. Casein phosphopeptide and amorphous calcium phosphate are both present (CPP-ACP). It can be used in place of preventative mouthwashes that include fluoride. There haven't been any studies that demonstrate how G.C. Tooth mousse affects the mechanical and surface qualities of these orthodontic wires, though. Thus, this study was aimed to evaluate and compare the corrosion and mechanical properties of Nickel titanium, Copper nickel titanium, β Titanium, Stainless steel and Australian 0.016" stainless steel wires immersed in FLUROVIL gel, PHOSFLUR mouth rinse and GC Tooth mousse with those immersed in Distilled water.

Objectives:

1. To evaluate and compare the change in the modulus of elasticity during the loading and unloading phase for five different Orthodontic wires as a result of exposure to prophylactic fluoride agents and GC Tooth mousse with Distilled water using 3 Point Bend Test.

2. To evaluate and compare the change in the yield strength during the loading and unloading phase for five different Orthodontic wires as a result of exposure to prophylactic fluoride agents and GC Tooth mousse with Distilled water using 3 Point Bend Test.

In the present published studies carried out in the past related to mechanical properties as well as related to corrosion of various Orthodontic wires by various chemical agents and oral environment, are reviewed.

Some reviews from previous studies

- A Goldberg, C Burstone[5] (1977) reported modulus of elasticity of stainless-steel Orthodontic wires was found to be 20% below the normally assumed range of 19.3 to 20.0 X 104 MPa (28.0 to 29.0 X 106 psi). Use of the latter value can result in significant computation errors in Orthodontic appliance mechanics. The lower modulus was attributed to severe cold drawing. The modulus of elasticity of the as received Orthodontic wires was 14.7 to 17.1 X 104 MPa (21.3 to 24.8 X 106 psi). This is approximately 20% below the generally accepted values of 19.3 to 20.0 X 104 MPa (28.0 to 29.0 X 106 psi) and can result in significant computational errors in Orthodontic appliance mechanics. Furthermore, these materials exceed their elastic limit at a stress which corresponds to 0.01% offset yield strength.
- Drake et al[6] (1982) tested the mechanical properties of three sizes of stainless steel (SS), nickel-titanium (NT), and titanium-molybdenum (TM) Orthodontic wires were studied in tension, bending, and torsion. The wires (0.016 inch, 0.017 by 0.025 inch, and 0.019 by 0.025 inch) were tested in the as-received condition. Tensile testing and stiffness testing machines along with a torsion instrument were used. In tension, the stainless steel wires had the least maximum elastic strain or springback, whereas the titanium-molybdenum wires had the most. Higher values of springback indicate the capacity for an increased range of activation clinically. In bending and torsion, the stainless steel wires had the least stored energy at a fixed moment, whereas the nickel-titanium wires had the most.
- EF Harris, SM Nuwman, J Nicholson[7] in 1988 investigated Changes in the mechanical properties of a nickel-titanium Orthodontic alloy, nitinol (0.016-inch arch wires), were studied in a simulated oral environment across time, at various levels of acidity, and at different amounts of static deflection. Significant decreases in specific mechanical properties were observed in these incubated wires compared with a group kept dry and unstressed. Ultimate tensile strain, modulus of elasticity, and 0.2% yield strength each decreased. Acidity (pH 3 to 7) and amount of deflection (0 to 4 mm in a 1 0-mm span) did not affect the wire, but there was a significant, monotonic decrease in yield strength with time in the simulated oral environment. By 4 months this measure of susceptibility to permanent deformation increased by 15%.
- Sunil Kapila, G Reichhold, S Anderson[8] (1991) conducted studies on effect of clinical recycling on mechanical properties of nickel-titanium alloy wires. Thirty wires each of nitinol and NiTi were subjected to a three - point bending test in as received condition and after one clinical exposure and two clinical exposures. One clinical exposure was defined as 8 weeks, plus or minus one week of clinical use. Wires undergoing two clinical uses were

cold sterilized after their first clinical exposure. Statistical analysis was done by one - factor repeated measures ANOVA and SCHIFFE F. test. Recycling produced significant changes in both the loading and unloading characteristics of NiTi wires, but only with the loading forces associated with nitinol wires.

- Yoneyama and H Doi[9] (1993) investigated the effect of heat treatment on the bending properties and transformation temperatures of Nickel-Titanium alloy wire, so that super elasticity could be used on Orthodontic appliances needing shape memory processes. A three point bending test and Differential Scanning Calorimetry (DSC) were performed. The transformation temperatures were lowered with increasing heat treatment temperature. The load in unloading process was less changeable and increased with the treatment temperatures between 733° -813° c. Secondary heat treatment in this range was suitable for using super elasticity in expansion arch appliances.

Materials and Methods

The study was carried out in the Department of Orthodontics and Dentofacial Orthopedics, SHARAD PAWAR DENTAL COLLEGE AND HOSPITAL, Sawangi (Meghe) Wardha in collaboration with Department of Metallurgy Engineering, VISVESVARAYA NATIONAL INSTITUTE OF TECHONOLOGY (VNIT), Nagpur. The material used for the study included five different types of wire, which are commonly used for Orthodontic treatment:-

1) 0.019" x 0.25" Nickel Titanium Wire
2) 0.019" x 0.25" Beta Titanium Wire
3) 0.019" x 0.25" Stainless Steel Wire
4) 0.019" x 0.25" Copper Nickel Titanium wire
5) 0.016 "A.J. WILCOCK. SPECIAL PLUS Australian wire

The topical applicants selected are commonly prescribed by the Orthodontists to their patients during Orthodontic treatment, to prevent demineralization of tooth or white spot lesions. (Photograph 1a and 1b) (Plate 1)

1. FLUROVIL gel (acidulated phosphate fluoride gel (APF gel) containing A stable aqueous gel providing 1.23% fluoride ion (derived from NAF and HF) (pH-4.1)
2. PHOSFLUR mouth rinse (Sodium fluoride and acidulated phosphate topical solution) 16 FL.OZ. (1PT) (pH-5.2)
3. GC Tooth mousse (Ingredients : pure water, glycerol, CPP-ACP, D-Sorbitol, CMC-Na, propylene glycol, Silicon dioxide, Titanium dioxide, Xylitol, Phosphoric acid, Flavouring agents, Zinc oxide, Sodium saccharin, Ethyl p-hydroxybenzoate, Magnesium oxide, Guar gum, propyl p- hydroxybenzoate, Butyl
   p- hydroxybenzoate (pH- Neutral-7).
   At the time study was conducted GC Tooth Mousse with fluoride was not introduced.

Equipments used

- Universal Testing machine, (Model No. 5582J5146, Instron; Canton Mass' USA, Photograph 2a and 2b) (Plate 2)

- Philips XL30 field emission SEM, Phillips Electron Optics, Hillsboro, Ore (Photograph 3a and 3b) (Plate 3)
- Merlin software program (Version 5.43) Instron.

Method

Table no.1 Total 120 wire samples of 50mm length were divided in following 4 groups

GROUP	TREATMENT MATERIAL	WIRE USED	SAMPLE NO.	TOTAL SAMPLE
Group A (control)	Distilled water	Nickel Titanium Wire	06	30
		Beta Titanium Wire	06	
		Stainless Steel Wire	06	
		Copper Nickel Titanium wire	06	
		0.016 " A.J. WILCOCK ss	06	
Group B (experimental group)	Phosflur	Nickel Titanium Wire	06	30
		Beta Titanium Wire	06	
		Stainless Steel Wire	06	
		Copper Nickel Titanium wire	06	
		0.016 " A.J. WILCOCK ss	06	
Group C (experimental group)	Flurovil	Nickel Titanium Wire	06	30
		Beta Titanium Wire	06	
		Stainless Steel Wire	06	
		Copper Nickel Titanium wire	06	
		0.016 " A.J. WILCOCK ss	06	
Group D (experimental group)	GC Tooth mousse	Nickel Titanium Wire	06	30
		Beta Titanium Wire	06	
		Stainless Steel Wire	06	
		Copper Nickel Titanium wire	06	
		0.016 " A.J. WILCOCK ss	06	

Control group:

Group A: Thirty (30) wire samples consisting of six (6) samples of each wire type were immersed in 10 ml DISTILLED WATER at 37^0 C in 5 test tube for 90 minutes.

Experimental groups:

Group B : Thirty (30) wire samples consisting of six (6) samples of each wire type was immersed in 10ml PHOSFLUR mouth rinse at 37^{0} C in 5 test tubes as per for 90 minutes.

Group C : Thirty (30) wire samples consisting of six (6) samples of each wire type was immersed in 10ml FLUROVIL gel at 37^{0} C in 5 test tubes as per for 90 minutes.

Group D: Thirty (30) wire samples consisting of six (6) samples of each wire type was immersed in 10ml GC Tooth mousse at 37^{0} C in 5 test tubes for 90 minutes.

The exposure time of 90 minutes is equivalent to three months of 1 minute daily topical fluoride application or fluoride rinse as stated by Mary Walker and Richard White in 2005. [10] Just before mechanical testing, the samples in the experimental group were removed from their solution, rinsed with Distilled water and placed in new, clean containers. Randomly selected samples from each wire type in the experimental and control group were tested using a 3 point bend test on a Universal Testing machine, (Model No. 5582J5146, Instron; Canton Mass' USA) The configuration of the 3 point fixture was a support span of 12 mm and 0.13 mm radii of each support and the striker. The specimens were tested in a heated chamber (37°C ± 1°C) to simulate the oral environment.

Each sample was loaded to a deflection of 3.1 mm and then unloaded to zero deflection at a cross head speed of 1mm/min. Load in Newton's (N) and deflection in (mm) were recorded every 100 ms for both loading and unloading of each sample by using the Merlin software program (Version 5.43) Instron. Load deflection curves were generated using this data. The Engineering Beam theory was used to calculate both modulus of elasticity (E) and yield strength (YS) [11]. The 'E' for loading and unloading slopes of each sample was calculated using the following equation:

E = $L^3m/4bd^3$ (GPA) where
L = Support span (mm)
b = Width of sample (mm)
d = Depth of sample (mm)
m = Slope of the straight line position of the loaded or unloaded – Deflection curve (N/mm of deflection)

Yield strength was also calculated from each loading and unloading portion of the curve.

The yield strength (YS) was calculated using the following the equation:

$$YS = \frac{3PL}{2bd^2}$$

P = Load at the apparent yield point (N)
L = Support span (mm)
b = Width of sample (mm)
d = Depth of Sample (mm)

The mean and Standard Deviation (SD) of the data was derived and their variances were statistically analysed using ANOVA.

Observations

Table 2: Loading and unloading properties of NiTi (0.019”× 0.25”) wire samples immersed in control and experimental groups.
(AT 37^{0}C)

Sr. No.	Sample description	LOADING		UNLOADING	
		Yield stress Mpa	Modulus of Elasticity, GPa	Yield stress Mpa	Modulus of Elasticity, GPa
1	Distilled water				
	Sample No.1	829.5	59.87	413	53.65
	Sample No.2	850.9	66.95	464.1	59.08
	Sample No.3	880.5	71.09	444.4	60.85
	Sample No.4	841	70.06	477.3	69.41
	Sample No.5	821.3	59.44	452.6	64.7
	Sample No.6	837.7	64.7	442.7	62.16
	Mean	843.483	65.3517	449.02	61.641
2	Phosflur gel				
	Sample No.1	845.8	64.7	403.2	57.46
	Sample No.2	845.9	63.78	402.7	57.53
	Sample No.3	841	63.53	403.8	53.39
	Sample No.4	844.3	65.55	404.5	54.33
	Sample No.5	852.5	64.06	405.8	57.62
	Sample No.6	813	58.59	404.3	56.16
	Mean	840.417	63.36833	404.05	56.08167
3	Flurovil				
	Sample No.1	837	61.68	386.8	55.39
	Sample No.2	838.9	62.43	386.5	57.44
	Sample No.3	836.8	61.98	388.4	57.84
	Sample No.4	837.2	60.17	376.7	58.59
	Sample No.5	839.5	61.07	395.4	50.32
	Sample No.6	837.2	62.41	398	50.78
	Mean	837.767	61.62333	388.6333	55.06
4	GC Tooth mousse				
	Sample No.1	826.99	63.04	453.2	53.35
	Sample No.2	841.04	65.01	443	59.08
	Sample No.3	830.2	65.07	422.8	61.25
	Sample No.4	851	64.05	443.9	61.41
	Sample No.5	861.01	65.94	445.3	64.04
	Sample No.6	842	65.96	476.2	62.03
	Mean	842.04	64.845	447.4	60.19333

Table 3: Loading and unloading properties of CuNiTi (0.019”× 0.25”) wire samples immersed in control and experimental groups. (AT 37^{0}C)

Sr. No.	Sample description	LOADING		UNLOADING	
		Yield stress Mpa	Modulus of Elasticity, Gpa	Yield stress, Mpa	Modulus of Elasticity, Gpa
1	Distilled water				
	Sample No.1	538.2	62.45	120.14	61.13
	Sample No.2	531.6	60.19	108.6	53.32
	Sample No.3	539.8	65.36	110.3	59.25
	Sample No.4	540.1	67.43	100.4	59.95
	Sample No.5	541.5	64.66	100.4	50.88
	Sample No.6	521.7	59.53	92.2	39.69
	Mean	535.483	63.27	105.34	54.0367
2	Phosflur gel				
	Sample No.1	527.1	62.21	92.09	44.84
	Sample No.2	532.9	61.61	94.12	51.63
	Sample No.3	524.8	61.69	92.04	41.38
	Sample No.4	521.5	61.53	94.1	58.39
	Sample No.5	529.7	60.31	93.08	52.95
	Sample No.6	529	60.3o	93.6	49.94
	Mean	527.5	61.47	93.171	49.855
3	Flurovil				
	Sample No.1	525.9	60.32	88.5	47.46
	Sample No.2	524.1	60.64	86.4	46.85
	Sample No.3	522.2	60.52	84.3	49.33
	Sample No.4	520.5	60.69	83.4	49.01
	Sample No.5	524.9	59.79	86.4	46.55
	Sample No.6	534.1	59.79	83.9	49.52
	Mean	525.28	60.2917	85.483	48.12
4	GC Tooth mousse				
	Sample No.1	538.01	62.93	109.9	60.05
	Sample No.2	539.99	63.03	99.01	56.09
	Sample No.3	537.23	63.05	119.94	56.93
	Sample No.4	532.56	59.99	107.96	54.02
	Sample No.5	539.52	65.06	101.04	51.08
	Sample No.6	522.01	60.03	91.9	43.09
	Mean	534.887	62.34833	104.9583	53.5433

Table 4: Loading and unloading properties of TMA (0.019”× 0.25”) wire samples immersed in control and experimental groups. (AT 37⁰C)

Sr. No.	Sample description	LOADING		UNLOADING	
		Yield stress Mpa	Modulus of Elasticity, Gpa	Yield stress, Mpa	Modulus of Elasticity, Gpa
1	Distilled water				
	Sample No.1	1854.8	65.64	1036.2	42.89
	Sample No.2	1779.1	59.44	1050	38.47
	Sample No.3	1851.5	59.72	961.2	41.47
	Sample No.4	1756.1	58.97	1031.9	44.39
	Sample No.5	1800.5	66.59	1046.7	39.12
	Sample No.6	1765.9	55.96	1022.1	39.03
	Mean	1801.317	61.0533	1024.68	40.895
2	Phosflur gel				
	Sample No.1	1846.6	58.21	961.1	40.07
	Sample No.2	1780.8	60.28	974.3	39.72
	Sample No.3	1790.1	60.17	1027	40.36
	Sample No.4	1805.4	60.28	1018.8	39.41
	Sample No.5	1781	61.01	983.7	40.13
	Sample No.6	1788.1	59.53	1086.2	39.64
	Mean	1798.667	59.9133	1008.517	39.8883
3	Flurovil				
	Sample No.1	1781.2	56.04	1002.2	38.66
	Sample No.2	1806.9	56.98	1003.6	37.81
	Sample No.3	1795.3	57.27	1002.1	37.52
	Sample No.4	1789	58.5	1003.4	38.57
	Sample No.5	1797.9	57.43	1003.9	38.38
	Sample No.6	1795.8	59.72	1002.1	37.41
	Mean	1794.35	57.6567	1002.88	38.0583
4	GC Tooth				
	Sample No.1	1755.2	60.72	960.9	40.07
	Sample No.2	1850.6	59.07	1030.9	40.02
	Sample No.3	1801	67.09	1047	40.01
	Sample No.4	1833.7	64.04	1035.9	42.01
	Sample No.5	1800.12	58.99	1037.96	39.07
	Sample No.6	1755.23	55	1021.9	38.99
	Mean	1799.308	60.818	1022.427	40.0283

Table 5: Loading and unloading properties of S.S. (0.019”× 0.25”) wire samples immersed in control and experimental groups. (AT 37^0C)

Sr. No.	Sample description	LOADING		UNLOADING	
		Yield stress MPa	Modulus of Elasticity, Gpa	Yield stress, Mpa	Modulus of Elasticity, Gpa
1	Distilled water				
	Sample No.1	2789.7	125.74	1706.7	85.93
	Sample No.2	2809.4	139.19	1734.7	91.01
	Sample No.3	2723.8	141.63	1701.8	88.66
	Sample No.4	2732.1	129.22	1699.4	86.52
	Sample No.5	2730.4	126.21	1798.4	82.82
	Sample No.6	2822.6	135.33	1756.1	84.99
	Mean	2768	132.8867	1732.85	86.655
2	Phosflur gel				
	Sample No.1	2759.5	127.34	1718.2	81.69
	Sample No.2	2755.5	131.38	1719.2	83.29
	Sample No.3	2781.4	119.25	1718.8	89.34
	Sample No.4	2756.2	137.78	1716.7	85.41
	Sample No.5	2753.3	137.12	1724.8	83.95
	Sample No.6	2779	132.04	1716.9	84.13
	Mean	2764.15	130.8183	1719.1	84.635
	Flurovil				
3	Sample No.1	2760.4	128.71	1717.2	82.29
	Sample No.2	2763.8	129.31	1713.9	83.76
	Sample No.3	2776.5	129.86	1705.7	83.64
	Sample No.4	2803.9	132.81	1707.9	83.97
	Sample No.5	2736.9	129.12	1709.3	82.39
	Sample No.6	2727.5	126.96	1719.5	83.71
	Mean	2761.5	129.4617	1712.25	83.2933
	GC Tooth mousse				
4	Sample No.1	2729.8	135.13	1703.2	85.65
	Sample No.2	2789.7	124.68	1705.6	83
	Sample No.3	2799.6	134.31	1733.9	86.99
	Sample No.4	2810.4	138.18	1733.6	84.91
	Sample No.5	2731.7	128.21	1673.3	86.98
	Sample No.6	2730.4	127.22	1837.2	85
	Mean	2765.267	131.2883	1731.133	85.4216

Table 6: Loading and unloading properties of Australian SS (0.019”× 0.25”) wire samples immersed in control and experimental groups. (AT 37^0C)

Sr. No.	Sample description	LOADING		UNLOADING	
		Yield strength Mpa	Modulus of Elasticity, GPa	Yield stress Mpa	Modulus of Elasticity, Gpa
1	Distilled water				
	Sample No.1	2368.1	108	1482.1	65.48
	Sample No.2	2317.5	103.78	1451.3	69.69
	Sample No.3	2382.2	106.14	1361.3	70.54
	Sample No.4	2297.8	123.36	1200.9	69.69
	Sample No.5	2323.2	105.42	1350	70.37
	Sample No.6	2320.3	111.7	1279.6	58.73
	Mean	2334.85	109.733	1354.2	67.4167
2	Phosflur gel				
	Sample No.1	2338.9	107.66	1243.1	60.03
	Sample No.2	2325.6	103.44	1231.9	65.81
	Sample No.3	2312.2	105.09	1223.4	60.37
	Sample No.4	2348.1	105.47	1202.3	68.52
	Sample No.5	2330.9	107.3	1175.6	63.49
	Sample No.6	2315	107.48	1203.8	65.6
	Mean	2328.45	106.073	1213.35	63.97
3	Flurovil				
	Sample No.1	2340	104.56	1192.5	61.6
	Sample No.2	2317.5	105	1167.2	63.36
	Sample No.3	2331.6	105.03	1220.6	62.9
	Sample No.4	2326.9	104.97	1172.8	60.5
	Sample No.5	2324.1	105.71	1184.1	60.48
	Sample No.6	2320.9	105.34	1220.6	
	Mean	2326.83	105.102	1192.97	61.7533
4	GC Tooth mousse				
	Sample No.1	2352.2	101.12	1351.2	72.54
	Sample No.2	2314.24	104.68	1349.2	70.34
	Sample No.3	2327.5	103.76	1441.2	67.67
	Sample No.4	2307.8	121.53	1216.6	67.78
	Sample No.5	2358.1	106.8	1479.3	64.45
	Sample No.6	2335.3	112.7	1281.6	57.68
	Mean	2332.52	108.432	1353.18	66.8133

Table 7: Statistical Significance mean values for the Loading and Unloading properties of the NiTi (0.019”× 0.25”) Wire samples immersed in distilled water (control) and experimental groups

	Solution	Mean(SD)			
		Loading yield strength(Mpa)	Loading Elastic Modulus(Gpa)	Unloading yield strength(Mpa)	Unloading Elastic Modulus(Gpa)
Ni-Ti Wire	Distilled water (control)	843.483	65.3517	449.02	61.641
		20.748	4.9613	21.90	5.3108
	Flurovil	837.767	61.62333	388.633*	55.06*
		18.466	3.2914	17.53	3.6537
	Phosflur	840.417	63.36833	404.05*	56.08167*
		13.944	3.9153	9.49	4.2155
	GC Tooth Mousse	842.04	64.845	447.23	60.397
		20.74	4.96	21.90	5.31

Significantly different from control: p< 0.0001*

Table 8: Statistical Significance mean values for the loading and unloading properties of the Cu-NiTi (0.019”× 0.25”) Wire samples immersed in distilled water (control) and experimental groups

	Solution	Mean(SD)				
		Loading yield strength(Mpa)	Loading Elastic Modulus(Gpa)	Unloading yield strength(Mpa)	Unloading Elastic Modulus(Gpa)	p-value
Cu-Ni-Ti Wire	Distilled water (control)	535.983	63.2700	105.34	54.0367	
		8.047	3.0904	9.74	8.1088	
	Flurovil	525.950	60.2917	85.483*	48.12*	
		7.036	1.8147	7.60	8.9680	
	Phosflur	527.5	61.47	93.171*	49.8555*	
		6.953	2.6046	7.77	7.4376	
	GC Tooth Mousse	534.887	62.8912	104.77	53.923	
		8.047	3.0904	9.74	8.1088	

Significantly different from control: p< 0.0001*

Table 9: Statistical Significance mean values for the loading and unloading properties of the TMA (beta-Titanium) (0.019”× 0.25”) Wire samples immersed in distilled water (control) and experimental groups

Beta Ti Wire(TMA)	Solution	Mean(SD)			
		Loading yield strength(Mpa)	Loading Elastic Modulus(Gpa)	Unloading yield strength(Mpa)	Unloading Elastic Modulus(Gpa)
	Distilled water (control)	1801.317	61.0533	1024.68	40.8950
		42.830	4.1558	32.70	2.4098
	Flurovil	1794.35	57.6567	1002.1	38.0583
		45.652	3.6011	14.13	2.1429
	Phosflur	1798.667	59.9133	1008.517	39.8883
		40.100	2.5445	53.95	1.5292
	GC Tooth Mousse	1799.308	60.818	1022.427	40.0283
		42.83	4.155	32.70	2.409

Significantly different from control: p< 0.0001*

Table 10: Statistical Significance mean values for the loading and unloading properties of the Stainless steel (0.019”× 0.25”) Wire samples immersed in distilled water (control) and experimental groups

Stainless steel wire	Solution	Mean(SD)			
		Loading yield strength(Mpa)	Loading Elastic Modulus(Gpa)	Unloading yield strength(Mpa)	Unloading Elastic Modulus(Gpa)
	Distilled water (control)	2768.000	132.8867	1735.52	86.3217
		44.332	6.8007	57.60	17.6810
	Flurovil	2761.5	129.462	1712.25	83.2933
		75.807	5.5478	24.41	12.1888
	Phosflur	2764.15	130.8183	1719.1	84.635
		31.122	6.8689	19.05	4.9590
	GC Tooth Mousse	2765.267	131.2883	1731.133	85.4216
		44.332	6.8007	57.60	17.6810

Significantly different from control: p< 0.0001*

Table 11: Statistical Significance mean values for the loading and unloading properties of the Australian Stainless steel (0.016”) Wire specimens in distilled water (control) and experimental fluoride agents and GC Tooth Mousse

AJ Wilcock SS wire	Solution	Mean(SD)			
		Loading yield strength(Mpa)	Loading Elastic Modulus(Gpa)	Unloading yield strength(Mpa)	Unloading Elastic Modulus(Gpa)
	Distilled water (control)	2334.850	109.7333	1354.20	67.4167
		32.768	7.2044	104.81	4.6481
	Flurovil	2326.833	105.102	1192.97*	61.75*
		19.266	2.6002	23.14	3.7031

	Phosflur	2328.45	106.0733	1213.35*	63.97*
		73.048	5.6208	24.34	3.4926
	GC Tooth Mousse	2332.52	108.432	1353.183	66.8133
		32.768	7.2044	104.81	4.6481

Significantly different from control: p< 0.0001*

Result

A study was conducted in Department of Orthodontics Sharad Pawar Dental College in collaboration with Department of Metallurgy, VNIT Nagpur. The samples of NiTi, Cu-NiTi, TMA (β-titanium), Stainless steel and Australian stainless steel wires were immersed in various solutions used for maintaining oral prophylaxis and analyzed for any change in surface morphology and mechanical properties. The prophylactic agents used were Flurovil, Phosflur and GC Tooth mousse. The alterations in Mechanical properties namely loading and unloading yield strength and modulus of elasticity was tested using 3 point bend test on universal testing machine in the Dept. of Metallurgy VNIT ,Nagpur.The data obtained was then statistically analyzed using one- way ANOVA to determine the significance of difference in the mechanical properties of the above mentioned wires.

Three Point Bend Test

1) NiTi wire samples:

Effect on unloading property:

Wire samples immersed in Flurovil showed unloading yield strength 388.633¬ ± 17.53 Mpa (P < 0.0001) and unloading modulus of elasticity 55.06 ± 3.65 Gpa (P < 0.0001) whereas wire samples immersed in Phosflur showed unloading yield strength 404.05± 9.49 Mpa (P <0.0001) and unloading modulus of elasticity i.e. 56.08 ± 4.2155 Gpa (P < 0.0001).

There was statistically significant reduction in the unloading yield strength and unloading modulus of elasticity of the wire dipped in Flurovil and phosflur as compared to samples exposed to Distilled water [unloading yield strength and modulus of elasticity was 449.02 ± 21.9 Mpa and 61.64 ± 5.31 Gpa respectively] (Table IA, IB). But Flurovil has more reduction in the unloading yield strength and modulus of elasticity as compared to Phosflur.

The NiTi wire samples exposed to GC Tooth mousse showed unloading yield strength 447.23± 21.90Mpa (P < 0.0001) and unloading modulus of elasticity i.e. 60.397± 5.31Gpa (P < 0.0001) which was similar or slightly reduce as compared to samples exposed to Distilled water [unloading yield strength and elastic modulus was 449.02 ± 21.9 Mpa and 61.64 ± 5.31 Gpa respectively]. (Table IA, IB).

Effect on loading property

Wire samples immersed in Flurovil showed loading yield strength 837.767± 18.466Mpa ($P < 0.0001$) and loading modulus of elasticity 61.62333± 3.2914Gpa ($P <0.0001$) whereas Wire samples immersed in Phosflur showed loading yield strength 840.417± 9.49 Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 63.36833± 3.9153Gpa ($P < 0.0001$).

There was no statistically significant reduction in the loading yield strength and loading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to sample exposed to Distilled water [loading yield strength and elastic modulus was 843.483± 20.748Mpa and 65.3517± 4.9613Gpa respectively] (Table IA, IB)

The NiTi wire samples exposed to GC Tooth mousse showed loading yield strength 842.04± 20.74Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 64.845± 4.96Gpa ($P <0.0001$) which was similar or slightly reduce as compare to sample exposed to Distilled water [loading yield strength and elastic modulus was 843.483± 20.748Mpa and 65.3517± 4.9613Gpa respectively] (Table IA, IB).

2) Cu-NiTi wire
Effect on unloading property:

Wire samples immersed in Flurovil showed unloading yield strength 85.483 ±7.60 Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 48.12 ± 8.9680 Gpa ($P < 0.0001$) whereas as wire samples immersed in Phosflur showed unloading yield strength 93.171 ± 7.77 Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 49.8555 ± 7.4376 Gpa ($P < 0.0001$).

There was statistically significant reduction in the unloading yield strength and unloading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to sample exposed to Distilled water [unloading yield strength and elastic modulus was 105.34± 9.74 Mpa and 54.0367± 8.1088. Gpa respectively]. (Table IIA, IIB) But Flurovil has more reduction in the unloading yield strength and modulus of elasticity as compared to Phosflur.

The Cu-NiTi wire samples exposed to GC Tooth mousse showed unloading yield strength 104.77± 9.74Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 53.923± 8.1088Gpa ($P < 0.0001$) which was similar or slightly reduce as compare to sample exposed to Distilled water [unloading yield strength and elastic modulus was 105.34± 9.74 Mpa and 54.0367± 8.1088. Gpa respectively].

Effect on loading property

Wire samples immersed in Flurovil showed loading yield strength 837.767± 18.466Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 61.62333± 3.2914Gpa ($P < 0.0001$) whereas Phosflur showed loading yield strength 840.417± 9.49 Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 63.36833± 3.9153Gpa ($P < 0.0001$).

There was no statistically significant reduction in the loading yield strength and loading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to samples exposed to Distilled water [loading yield strength and elastic modulus was 843.483± 20.748Mpa and 65.3517± 4.9613Gpa respectively] (Table IIA, IIB.)

The Cu-NiTi wire samples exposed to GC Tooth mousse showed loading yield strength 842.04± 20.74Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 64.845± 4.96Gpa ($P < 0.0001$) which was similar or slightly reduce as compare to samples exposed to Distilled water [loading yield strength and elastic modulus was 843.483± 20.748Mpa and 65.3517± 4.9613Gpa respectively] (Table IIA, IIB)

3) TMA (Beta titanium) wire samples:

Effect on unloading property:

Wire samples immersed in Flurovil showed unloading yield strength 1002.1± 14.13Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 38.0583± 2.1429Gpa ($P = 0.0001$) whereas wire samples immersed in Phosflur showed unloading yield strength 1008.517± 53.95Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 39.8883± 1.5292Gpa ($P < 0.0001$).

There was no statistically significant reduction in the unloading yield strength and unloading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to sample exposed to Distilled water [unloading yield strength and elastic modulus was 1024.68± 32.70Mpa and 40.8950± 2.4098Gpa respectively] (Table IIIA, IIIB).

The TMA (β-titanium) wire samples exposed to GC Tooth mousse showed unloading yield strength 1022.427± 32.70Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 40.0283± 2.409Gpa ($P < 0.0001$) which was similar or slightly reduce as compared to samples exposed to Distilled water. [Unloading yield strength and elastic modulus was 1024.68± 32.70Mpa and 40.8950± 2.4098Gpa respectively] (Table IIIA, IIIB).

Effect on loading property:

Wire samples immersed in Flurovil showed loading yield strength 1794.35± 45.652Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 57.6567± 3.6011Gpa ($P < 0.0001$) whereas Phosflur showed loading yield strength 1798.667± 40.100Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 59.9133± 2.5445Gpa ($P < 0.0001$). (Table IIIA, IIIB).

There was no statistically significant reduction in the loading yield strength and loading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to samples exposed to Distilled water [loading yield strength and elastic modulus was 1801.317± 42.830Mpa and 61.0533± 4.1558Gpa respectively] (Table IIIA, IIIB).

The TMA (β-titanium) wire samples exposed to GC Tooth mousse showed loading yield strength 1799.308± 42.83Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 60.818± 4.155Gpa ($P < 0.0001$) which was similar or slightly reduce as compare to samples exposed to Distilled water [loading yield strength and elastic modulus was 1801.317± 42.830Mpa and 61.0533± 4.1558Gpa respectively] (Table IIIA, IIIB).

4) Stainless Steel wire;
Effect on unloading property:

Wire samples immersed in Flurovil showed unloading yield strength 1712.25± 24.41Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 83.2933± 12.1888Gpa ($P < 0.0001$) whereas wire samples immersed in Phosflur showed unloading yield strength 1719.1± 19.05Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 84.635± 4.9590Gpa ($P < 0.0001$).

There was no statistically significant reduction in the unloading yield strength and unloading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to samples exposed to Distilled water [unloading yield strength and elastic modulus was 1735.52± 57.60Mpa and 86.3217± 17.6810Gpa respectively] (Table IVA, IVB)

The Stainless steel wire samples exposed to GC Tooth mousse showed unloading yield strength 1731.133± 57.60Mpa ($P < 0.0001$) and unloading modulus of elasticity i.e. 85.4216± 17.6810Gpa ($P < 0.0001$) which was similar or slightly reduce as compared to samples exposed to Distilled water [unloading yield strength and elastic modulus was 1735.52± 57.60Mpa and 86.3217± 17.6810Gpa respectively] (Table IVA, IVB)

Effect on loading property:

Wire samples immersed in Flurovil showed loading yield strength 2761.5± 75.807Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 129.462± 5.5478Gpa ($P < 0.0001$) whereas Phosflur showed loading yield strength 2764.15± 31.122Mpa ($P < 0.0001$) and loading modulus of elasticity i.e. 130.8183± 6.8689 Gpa ($P < 0.0001$).

There was no statistically significant reduction in the loading yield strength and loading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to samples exposed to Distilled water [loading yield strength and elastic modulus was 2768.000± 44.332Mpa and 132.8867± 6.8007Gpa respectively] (Table IVA, IVB).

The Stainless steel wire samples exposed to GC Tooth mousse showed loading yield strength 2765.267± 44.332Mpa ($P < 0.0001$) and loading modulus of elasticity i.e131.2883± 6.8007Gpa ($P < 0.0001$) which was similar or slightly reduce as compare to samples exposed to Distilled water [loading yield strength and elastic modulus was 2768.000± 44.332Mpa and 132.8867± 6.8007Gpa respectively] (Table IVA, IVB)

5) Australian Stainless Steel wire;
Effect on unloading property:

Wire samples immersed in Flurovil showed unloading yield strength 1192.97 ± 23.14 Mpa (P < 0.0001) and unloading modulus of elasticity 61.75± 3.7031Gpa (P < 0.0001) whereas wire samples immersed in Phosflur showed unloading yield strength 1213.35± 24.34Mpa (P <0.0001) and unloading modulus of elasticity i.e. 63.97± 3.4926Gpa (P < 0.0001).

There was statistically significant reduction in the unloading yield strength and unloading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to samples exposed to Distilled water [unloading yield strength and elastic modulus was 1354.20 ± 104.81 Mpa and 67.4167± 4.6481Gpa respectively] (Table VA, VB). But Flurovil has more reduction in the unloading yield strength and modulus of elasticity as compared to Phosflur.

The Australian stainless steel wire samples exposed to GC Tooth mousse showed unloading yield strength 1353.183± 104.81Mpa (P < 0.0001) and unloading modulus of elasticity i.e. 66.8133± 4.6481Gpa (P < 0.0001) which was similar or slightly reduce as compared to samples exposed to Distilled water [unloading yield strength and elastic modulus was 1354.20 ± 104.81 Mpa and 67.4167± 4.6481Gpa respectively] (Table IVA, IVB)

Effect on loading property:

Wire samples immersed in Flurovil showed loading yield strength 2326.833± 19.266Mpa (P < 0.0001) and loading modulus of elasticity i.e. 105.102± 2.6002Gpa (P < 0.0001) whereas wire samples immersed in Phosflur showed loading yield strength 2328.45± 73.048Mpa (P < 0.0001) and loading modulus of elasticity i.e. 106.0733± 5.6208Gpa (P < 0.0001).

There was no statistically significant reduction in the loading yield strength and loading modulus of elasticity of the wire dipped in Flurovil and Phosflur as compared to samples exposed to Distilled water [loading yield strength and elastic modulus was 2334.850± 32.768Mpa and 109.7333± 7.2044Gpa respectively] (Table VA, VB)

The Australian Stainless steel wire samples exposed to GC Tooth mousse showed loading yield strength 2332.52± 32.768Mpa (P <0.0001) and loading modulus of elasticity i.e108.432± 7.2044Gpa (P < 0.0001) which was similar or slightly reduce as compare to samples exposed to Distilled water [loading yield strength and elastic modulus was 2334.850± 32.768Mpa and 109.7333± 7.2044Gpa respectively] (Table VA, VB).

Discussion

The history of technical development in Orthodontics has been marked by a continuing search to improve Orthodontic treatment and also to provide best health care protocol. Vast range of new materials have been introduced in contemporary Orthodontic practice along with new approaches to prevent the unwanted side effects i.e. white spot lesions of enamel surface where brackets are bonded. Orthodontic wires have progressed from Nickel-Chromium-Iron, Stainless steel alloy to Nickel-Titanium, Beta-Titanium, Copper-NiTi, Elgiloy, Chinese NiTi etc. With the introduction of NiTi wires in 1960's by Buehler of Naval ordinance lab 4, the spectrum of achieving various tooth movements have increased due to the properties of titanium like, Super elasticity, Thermal shape memory, Good corrosion resistance. etc. Right from its inception into Orthodontic practice, various studies have been carried out on Titanium based alloys to evaluate changes in the mechanical properties and surface topography upon their exposure to prophylactic agents. Orthodontic tooth movement is basically dependent on mechanical properties of arch wire namely modulus of elasticity and yield strength.[12,13]

Each sample was loaded to a deflection of 3.1 mm and then unloaded to zero deflection at a cross head speed of 1mm/min. Load in Newton's (N) and deflection in (mm) were recorded every 100 ms for both loading and unloading of each sample by using the Merlin software program (Version 5.43) Instron. Load deflection curves were generated using this data. The Engineering Beam theory was used to calculate both modulus of elasticity (E) and yield strength (YS).[14] The NiTi and Cu-NiTi absorbs hydrogen due to the high affinity of titanium to hydrogen. This absorbed hydrogen is known to prevent martensitic transformation as the transformation is sensitive to the presence of interstitial atoms. There was also a marked reduction in the loading and unloading yield strength / modulus of elasticity of Titanium based alloy dipped fluoride were compared to the control group.

Though the reduction in loading yield strength and modulus of elasticity was not statistically significant, but more reduction was seen in all three titanium based alloys (NiTi, Cu-NiTi, β-Titanium) associated with Flurovil.There was a statistically significant reduction in the unloading yield strength and unloading modulus of elasticity with NiTi and Cu-NiTi wires (Table 2A and 2B) associated with Flurovil and Phosflur, but more reduction was observed associated with Flurovil. Not much reduction in the unloading yield strength and modulus of elasticity was observed associated with beta titanium wires. The ratio of yield strength and modulus of elasticity are closely associated with the spring back properties of Orthodontic wires. These properties makes the wire desirable in condition where large deflection and low force are required i.e. alignment and leveling stage where the wide working range and elastic recovery is desired.Beta titanium wire has lower working range than NiTi but higher formability and is therefore used in (stage II and stage III) i.e. intermediate treatment phase.

From practical point of view loading cycle represents the force which the clinician applies on the teeth while deflecting and ligating the wire in the brackets.The unloading cycle is very important as it shows the potential tooth movement as the wire returns to its original position. Reduction in the unloading yield strength would then indicate that the wire will fail to return to its original shape thus prolonging or delaying tooth movement. This would mean longer time required for Orthodontic correction.

The unique feature of NiTi alloy is its super elastic property, where the stress value remains constant when the wire is deformed beyond a limit and at the same time it remains constant when the deformation rebounds. This property is affected due to corrosion caused by hydrogen embrittlement in presence of fluoride.As seen in our study the use of fluoride significantly reduces the unloading yield strength and modulus of elasticity.Therefore whenever using NiTi or Cu-NiTi the use of fluoride mouth rinses should be avoided or substituted with something less corrosive. Moreover if fluoride is to be used one should prefer the solution form (Phosflur) with less acidic pH, alternatively if fluoride mouth rinses are to be used they should be prescribed twice a week instead of daily or other fluoride should also be reduced from daily to twice a weak whenever using, Titanium based alloys.There was no significant difference in the SEM image of wire dipped in G C tooth mousse when compared to control group. There was also no change in the loading yield strength /modulus of elasticity and unloading yield strength /modulus of elasticity of wire immersed in GC Tooth mousse.It also claimed that Tooth mousse is a good agent which brings about remineralization and the one without fluoride can be substituted in place of fluoride mouth rinses when using Titanium based arch wires.

Conclusion

The following conclusions were drawn:

- During unloading, reduction in yield strength and modulus of elasticity values were observed in all the wires but was found statistically significant in NiTi, CuNiTi and AJ Wilcock SS wires.
- During loading, reduction in yield strength and modulus of elasticity values were observed in all the wires but was not statistically significant.
- NiTi, CuNiTi and AJ Wilcock SS wires immersed in Flurovil showed greater reduction in yield strength and modulus of elasticity values as compared to Phosflur, GC Tooth mousse.
- GC Tooth mousse showed least reduction in the yield strength and modulus of elasticity values, during unloading and loading, as compared to other oral prophylactic agents in all the wires.
- GC Tooth mousse showed slightly less or similar reduction in the yield strength and modulus of elasticity values, during unloading and loading, as compared to distilled water (control) in all the wires.

This study suggests that fluoride prophylactic agents, inspite of their established caries preventing activity, must be used with caution in patients undergoing Orthodontic treatment. Extensive use of these agents may cause corrosive effects on the Orthodontic wire surfaces with deterioration of their mechanical properties. This may possibly result in an increase in the overall treatment time. Also on the basis of the findings of this study it is suggested to use G C Tooth Mousse as a prophylactic agent against the use of fluoride containing agents because of its negligible side effects on the properties of the wire surface.There is scope beyond the preview of this study to evaluate the phenomenon of hydrogen embrittlement of Orthodontic wires which could possibly be responsible for the deterioration of the mechanical properties, via the method of hydrogen thermal desorption analysis. Also, Nickel sensitivity in patients has been documented.

Hence the amount of Nickel leaching out due to surface corrosion of NiTi and CuNiTi wires caused by fluoride agents can be evaluated in further studies.

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