Journal of Research in Medical and Dental Science
2026, Volume 14, Issue 1, Page No: 01-13

Available Online at: www.jrmds.in
eISSN No. 2347-2367: pISSN No. 2347-2545

Unaltered Frictional Force Between Graphene Oxide-Coated Stainless Steel Wires and Orthodontic Bracket in Acidic pH

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ABSTRACT

The pH of the saliva has been an important consideration in the physical and chemical behavior of orthodontic components, specifically, in the frictional force of wires. In orthodontics, any material that reduces friction is generally favorable. Graphene Oxide (GO) is a promising nano-material for its anti-corrosive property. The purpose of this study was to evaluate the effect of pH on frictional force of GO-coated stainless steel (ss) wires. This study tested a total of 60 straight 0.017 x 0.025 ss orthodontic wires. Samples were divided into 2 major groups: G1- uncoated and G2-GO-coated ss wires. Spray technique was used to coat the experimental group (G2) with GO. Each group was further subdivided into 2 subgroups, G1A, G2A and G1B and G2B with 15 samples each. The groups G1A and G2A were soaked in artificial saliva with a pH of 5.5, while groups G1B and G2B were soaked in artificial saliva with a pH of 6.8 for 24 hours. The samples were stored in an incubator with a temperature maintained at 37°C for 21 days. SEM was performed randomly in two pre-test and post-test samples from each subgroup. A pull test utilizing the Universal Testing Machine was employed to measure the frictional force of the samples. ANOVA was used to compare friction force of the uncoated and GO-coated wires at different pH levels with a confidence interval of 95% and a p-value of ≤ 0.05. The results of the current study concluded that there was no difference in frictional force between GO-coated (pH5.5 M=1.46, SD=0.22; pH6.8 M=1.35, SD=0.08) and uncoated (pH5.5 M=1.49, SD=0.28; pH6.8 M=1.38, SD=0.14) wires at different pH levels.

Keywords: Graphene Oxide, frictional force, pHgender, KSU.

HOW TO CITE THIS ARTICLE: Ahmed Mohamed Fadl Abozor, Ann Larae Querijero, Unaltered Frictional Force Between Graphene Oxide-Coated Stainless Steel Wires and Orthodontic Bracket in Acidic pH. J Res Med Dent Sci, 2026; 14(1):01-13.

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Received: 07-May-2026, Manuscript No. jrmds-26-189436;

Editor assigned: 10-May-2026, Pre QC No. jrmds-26-189436(PQ);

Reviewed: 07-May-2026, QC No. jrmds-26-189436(Q);

Revised: 07-May-2026, Manuscript No. jrmds-26-189436(R);

Published: 29-May-2026

INTRODUCTION

Background of the Study

Orthodontics is a specialty of Dentistry that deals with the diagnosis, prevention and correction of malposition of teeth and jaws. Tooth movement is achieved with the use of orthodontic attachments (i.e. brackets, molar bands, etc.) and wires.

Friction is the resistance to sliding generated at the wire-bracket interface that has a bearing on the force transmitted to the teeth. For teeth to move, they require a slow continuous force to move along the wire. In sliding mechanics, tooth movement is achieved by guiding a tooth along a continuous arch-wire with the use of a bracket. The friction that is generated at bracket-wire interface restricts tooth movement in the desired direction. For the clinicians practicing friction mechanics, it becomes necessary to understand the friction produced at bracket-wire interface in order to accelerate the tooth movement [1].

Burstone in 1981 presented several factors and characteristics that should be taken into consideration when choosing orthodontic wires. These are thickness, cross-sectional shape, metal alloy composition, inter bracket distances, types of ligatures, bracket size, friction between wire and bracket horizontally and vertically, arch wire curvature and stress-to-strain ratio at any point, was called as modulus of elasticity. Stainless steel alloy is one of the most commonly used wires in orthodontics. It has a high yield strength, high modulus of elasticity, good resistance to corrosion, moderate cost, biocompatible, excellent formability and weldability [2].

Developments in orthodontic materials have introduced coated wires for esthetics. As well, advancements on mechanical and anti-corrosive property were also established. In a study conducted by [3], they noted that coating decreases corrosion and coated arch wires can be used for patients allergic to nickel. Various types of coated arch wires are available in the market today such as epoxy resin, polytetrafluoroethylene (Teflon), rhodium and fiber reinforced polymer. Studies have shown that coated wires may be able to generate similar or improved properties to non-coated arch wires.

The use of Graphene in the field of Dentistry is currently being investigated for its latent application in biomaterials. Tested Graphene as a coating material [4]. Graphene was able to become a protective coating against scratch or other physical damage toward a substrate. Graphene was also proven to be an effective corrosion barrier material since it was considered inert under the conditions where chemical reactions of other substrates will take place. As a result, it is also promising in improving the anti-corrosion property of a coating system. Similarly, in a study conducted by [5], they stated that Graphene coating effectively suppresses metal oxidation by oxygen reduction and metal salt solution. Most importantly, Graphene sheets can protect the polymer underneath from atomic oxygen (AO) erosion because they pose a high energy barrier to AO diffusing from the top of the graphene sheets to the reactive polymer surface underneath. These results indicate the functional capabilities of Graphene as effective corrosion-inhibiting materials.

With this, Graphene Nanosheets (GNS)-based epoxy resin coating is expected to be a suitable anticorrosive material. Graphene Oxide contains hydrophobic graphene domains and hydrophilic edges anchored with carboxyl groups, which will give a wide range of chemical functionalization opportunities and good water dispersibility. It has been widely explored for their antimicrobial properties due to their unique chemical and physical properties.

The composition of saliva and its properties can be affected by many variables such as physiological nutritional factors, diet and salivary flow. Hormones, drugs and various diseases can also influence saliva. The oral cavity is damp, coupled with the fluctuations and variability of the pH, it may help trigger undesirable reactions produced by the response to this environment. This may be evident in the acceleration of the process of corrosion in metals. The surface defects of the wires may initiate corrosion, plaque build-up and possibly an increase in the release of unwanted ions in the oral cavity. The wire used in orthodontics must withstand mechanical, thermal and chemical stresses as oral environment favors biodegradation of metal alloys. The superficial roughness can also alter the effectiveness in orthodontic movement, mainly because the surface defects may interfere with friction, and consequently, can influence unfavorably on the sliding mechanics. Stainless steel alloys of cobalt chromium and titanium are used due to the formation of a passive surface film of oxide that contributes to a greater resistance to corrosion. Without being completely infallible at higher pH, the corrosion current of basic metal alloys decreases due to alloy passivation [6].

Various studies concluded that mechanical properties of the wires can be changed because of corrosion caused by some substances, like fluoride and chlorohexidine used in the oral cavity during orthodontic treatment and Consequently, realizing the anti-bacterial and anti-corrosive properties of the Graphene Oxide, the researcher investigated the effect of different pH levels on the frictional force of Graphene Oxide-coated stainless steel wires [7].

Statement of the Problem

How does pH affect the frictional force of Graphene Oxide (GO) coated stainless steel wires?

Objectives

General: To evaluate the frictional force of Graphene Oxide-coated stainless steel wires using pulling test.

Specific:

1. To measure the frictional force of uncoated ss wires exposed to pH 5.5.
2. To measure the frictional force of uncoated ss wires exposed to pH 6.8.

3. To measure the frictional force of Graphene Oxide-coated ss wires exposed to pH 5.5.
4. To measure the frictional force of Graphene Oxide-coated ss wires exposed to pH 6.8.
5. To compare the frictional force of uncoated and Graphene Oxide-coated ss wire exposed to pH 5.5.
6. To compare the frictional force of uncoated and Graphene Oxide-coated ss wire exposed to pH 6.8.

Hypothesis

The pH has an effect on the frictional force of Graphene Oxide-coated ss wires.

Scope

This study was confined in investigating the frictional force of uncoated and GO-coated straight stainless-steel wires with the size of 0.017 x 0.025 at different pH levels [8]. Roth 022 slot brackets were used to hold the wire in place during the pulling test and secured with a 0.09 ligature wire twisted five times. The GO was bought in a premixed liquid solution of 1.5g/ml concentration.

Limitations

This study was limited to straight stainless-steel wires with a size of 0.017 x 0.025. Coating was performed only on the ss arch wire. The brackets and ligature wires were excluded from the aforementioned coating procedure. Although elastic modules are a more popular choice in a normal day-to-day clinical practice, ligature wire was opted for this experiment.

Significance of the Study

This study will benefit orthodontists by educating them of the effects of pH on certain orthodontic components. As well, it will allow them to be acquainted with promising materials that can be incorporated in the clinical practice.

Maximizing the use of the wire due to its anti-corrosive property will be cost effective and consequently, minimize treatment time beneficial not only to the orthodontic practitioner but to the patient as well by optimizing treatment outcomes[9].

LITERATURE REVIEW

Stainless steel wires

Stainless steel alloys are one of the most commonly used wires in orthodontics. It is has a high yield strength, high modulus of elasticity, good resistance to corrosion, moderate cost, biocompatible, excellent formability and weldability.

Compared the physical, mechanical, and flexural properties of stainless steel, titanium-molybdenum alloy and beta-titanium alloy [10]. They concluded that stainless steel was the smoothest wire; it had the lowest friction and spring-back values and high values for stiffness (which prevents deformation), ultimate tensile strength, modulus of elasticity and yield strength.

Compared the static frictional resistance between three modern orthodontic brackets ceramic with gold-palladium slot, ceramic, and stainless steel and four arch wires (0.019 x 0.025 in) stainless steel, nickel-titanium, titanium molybdenum alloy (TMA), and low-friction colored TMA: they found that TMA wire showed highest frictional resistance and ss wire showed the lowest, frictional values[11]. Even the SEM examination of the arch wire surfaces at 1000x magnification showed the smoothest surface with the ss wire followed in decreasing order by NiTi, colored TMA, and TMA.

Frictional resistance of coated and uncoated orthodontic wires

Evaluated and compared the frictional properties and surface characteristics of honeydew and purple colored (ion implanted) TMA wires with uncoated TMA wires. They found colored ion-implanted TMA wires; especially honeydew TMA wires have low friction and improved surface finish [12]. Hence, these can be used in frictionless as well as sliding mechanics, however uncoated TMA wires are inefficient.

Evaluated the effect of total wire dimension with the type and thickness of coating layer on friction of coated stainless-steel wires. They used two sizes of wires, 0.016 × 0.022 inch and 0.019 × 0.025 inch, and pulled the wire through a set of ceramic brackets using a Universal Testing Machine. The results of their study showed that the frictional forces of fully coated Teflon wires produced the least amount of friction.

Studied the frictional behavior of eight coated wires of different dimensions [13]. The coatings were made of Teflon and by ion implantation and they finalized that all coatings can reduce frictional losses compared with an uncoated reference wire by the same manufacturer.

Compared the frictional resistance of silver coated and uncoated stainless-steel wires (.017 x .025 and .019 x .025). They found that overall silver coating either did not affect the frictional resistance (0.017 × 0.025-inch ss wires) or reduced it (0.019 × 0.025-inch coated ss wires) compared to uncoated wires [14].

Graphene Coating

In a study conducted by, it was noted that coating decreases corrosion and coated arch wires can be used for patients allergic to nickel, when coatings are sustained. While proposed that the wires coated with nanoparticles might offer a novel opportunity to substantially reduce friction during tooth movement [15]. A few tests were undertaken to evaluate toxicity of the fullerene-like nanoparticles and have provided indications that they might be biocompatible. SEM/EDS analysis of the coated wires showed clear impregnation of the IF-WS2 nanoparticles in the Ni–P matrix. The friction coefficient measured by the ball-on-flat tribometer was significantly reduced (from 0.25 to 0.08).

Coated polyester substrate by Graphene Oxide using spray coating machine with the following protocol[16]. The peripheral of the polyester substrate was secured on a Polypropylene petri dish during spraying process using adhesive tape. The inlet pressure of air was regulated at 50 psi. The airbrush tip was placed vertically at 15 cm from the substrate and thus the tiny droplets of the sprayed solution covered the entire cross section of the mounted substrate. Spray deposition was carried out for 2 s, and a rest period of 5 s was given for the solvent to evaporate by the air continuously coming out of the airbrush, and they repeated this cycle 10 times [17].

Tested graphene as a coating material. Graphene was able to become a protective coating against scratch or other physical damage toward a substrate [18]. Graphene was also proven to be an effective corrosion barrier material because it was considered inert under the conditions where chemical reactions of other substrates will take place. As a result, it is also promising in improving anti-corrosion property of a coating system.

Explored the effects of GO (1.5 mg/ml) and rGO coated with titanate nanonetwork on Ti implants [19]. The result of this study showed differentiation and proliferation of the rats' cells, which signified the biocompatibility of GO and it adhered to the implant.

Salivary pH Evaluated the effects of different salivary pH 2.0, 5.0 and 7.6 on the surface of orthodontic wires titanium-molybdenum alloy (TMA), and CrNi stainless steel. The results showed that the lower pH, the more roughness was found. In the evaluation of SEM, changes were found on the surface of TMA wires with pH 2 and 5. The steel wires had no superficial changes.

Also evaluated the effect of pH and temperature on orthodontic NiTi arch wires after immersion in an acidic fluoride solution. They found that the volumetric weight change, concentration of the released elements, and surface morphology were influenced by pH and temperature. At pH 3.5 of 60°C solution, the greatest weight loss, release of elements, and corrosion of surface occurred from the wires. At pH 6, on the other hand, no such loss or release occurred regardless of temperature.

Studied the effect of wire bending and salivary pH on the surface and mechanical properties of orthodontic stainless steel arch-wires [20]. There was a significant interaction effect of bending and pH on flexural Young's moduli of stainless steel arch-wires. Moreover, bigger surface irregularities were seen on SEM images of straight wires immersed in artificial saliva at pH 5.6 compared to artificial saliva at other pH values (6.6 and 7.6). Finally, pH plays a synergistic effect on the change of mechanical properties of stainless steel (SS) wires along with wire bending.

Graphene Oxide

Graphene Oxide has been widely explored for their distinctive antimicrobial characteristic due to their unique chemical and physical properties. Its apparently low toxicity enabled graphene oxide materials to be promising candidates for the next generation of antimicrobial agents. This coincides with different studies that have shown that graphene oxide and its derivatives exhibit broad-spectrum antimicrobial activity against bacteria and fungi.

Studied the super-flexibility of graphene oxide, and they concluded that the super-flexibility of GO could dramatically reduce the bending rigidity. Such super-flexibility is expected to be a significant advantage for the development of functional and highly bendable coatings, films, and fibers based on GO flakes. Graphene Oxide showed its antimicrobial property and inhibitory factor to wires from corrosion.

Stated that graphene coating effectively suppresses metal oxidation by oxygen reduction and metal salt solution. Most importantly, graphene sheets can protect the polymer underneath from atomic oxygen (AO) erosion because it presents a high energy barrier to AO diffusing from the top of the graphene sheets to the reactive polymer surface underneath [21]. These results indicate the functional capabilities of graphene as an effective corrosion-inhibiting material. With this, graphene nanosheets (GNS)-based epoxy resin coating is expected to be a suitable kind of anticorrosive material.

Definition of Terms

- ***Frictional force*** **-** the resistance to sliding generated at the wire-bracket interface that has a bearing on the force transmitted to the teeth.
- ***Graphene Oxide*** – a chemical substance that possess an antimicrobial and anticorrosion properties that was sprayed on the stainless steel wires and tested for frictional resistance.
- ***pH*** – the level at which the coated and uncoated wires were immersed in (5.5 and 6.8) during the experiment.
- ***Spray technique*** - a coating method which utilized a spray gun to create an electrical charge on solution particles of GO to adhere to the stainless-steel wires.
- ***Dipping Technique*** – coating method in which the stainless steel wire is immersed and soaked in GO (Figure 1,2).

MATERIALS AND METHODS

Research Design

This study adopted an experimental design, using a post-test control group, to evaluate the frictional force (dependent variable) of GO-coated and uncoated wires (independent variable) on different pH levels of saliva (independent variable).

Research Locale

Sample preparation was conducted at the 5th floor Graduate Dentistry Research Laboratory, College of Dentistry, Lucio Tan building, UE Manila. The frictional force was tested using a Universal Testing Machine at the University of Philippines, Diliman, Quezon City.

Pilot Test

The wires were coated using 2 different coating techniques - spray and dipping techniques, to check the adhesion of GO to the stainless-steel wires. Three wires were tested (uncoated wire, coated wire using spray technique and coated wire using dipping technique). The wires were mechanically

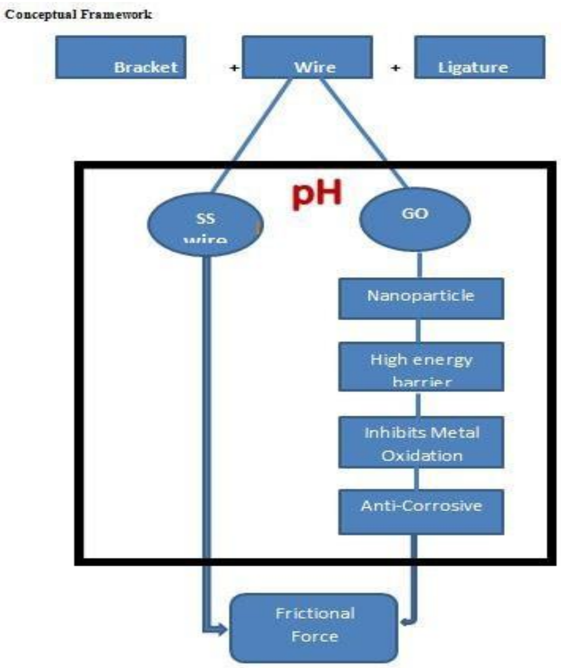

Figure 1. Conceptual Framework.

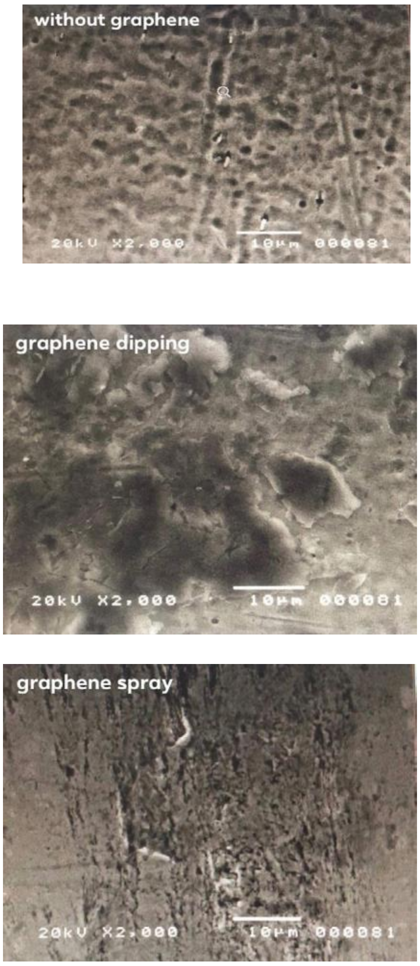

Figure 2. Surface morphology of the wires.

brushed and stored in distilled water for three days prior to subjecting it to SEM analysis.

Examination using SEM was performed at De La Salle University to confirm the adherence of GO to the wires. 2000x power of magnification was preferred in evaluating the surface morphology of the wires. The following results were seen:

The results showed the presence of GO on the wires that were coated using spray and dipping methods. Of the two aforementioned coating methods utilized in the pilot test, spraying method was selected and deemed appropriate for this study, as it showed a more homogenous GO coating on the stainless steel wire compared to the dipping technique.

Instrumentation

Procedure

The samples were mounted on a Universal Testing Machine and underwent a pulling test to simulate the sliding mechanics and to obtain the frictional force (dependent variable) of GO-coated and uncoated wires (independent variable). The different pH levels of the artificial saliva (independent variable) were closely monitored and maintained (two times a day) using a pH meter. A buffering solution was added to the artificial saliva to maintain the required pH whenever changes in its levels were observed.

Sixty straight stainless-steel wires were divided into two groups, Group 1 – uncoated stainless-steel wires (control) and Group 2 – GO-coated stainless steel wires using the spraying technique. The two groups were then subdivided into two: G1A – uncoated ss wires in pH 5.5 artificial saliva (15 samples), G1B – uncoated ss wires in pH 6.8 artificial saliva (15 samples) and G2A – GO-coated ss wires in pH 5.5 artificial saliva (15 samples), G2B – GO-coated ss wires in pH 6.8 artificial saliva (15 samples).

Coating of GO

To prepare G2A and G2B groups for GO coating, the stainless-steel wires were cleansed and dipped in acetone for 2 minutes followed by distilled water for 2 minutes. This cycle was repeated 5 times, after which, the samples were placed in a dry-heat oven for 15 minutes at 60°C to dry. The samples were then placed to the substrate holder to commence spray deposition. A coating machine was automated to perform a 10x cycle of 2 seconds GO spraying followed by 5 seconds rest time. Since the wire was rectangular in shape, the cycles were repeated in every surface following the same coating protocol. All experimental groups were coated in the same manner. After the coating was completed, the samples were kept in an incubator at 37°C for 24 hours.

Pretest SEM

Two samples each from G1 and G2 underwent SEM cross-sectional view at 150x, 350x and 1000x magnification. This was a randomized pretest control of the samples to check if GO adhered to the surface of the stainless steel wires.

Soaking of the samples

The samples were soaked in artificial saliva for 24 hours continuously for 21 days in an incubator at 37 °C. Group G1A and G2A were soaked in pH 5.5 artificial saliva and G1B and G2B were soaked in pH 6.8 artificial saliva. The pH of artificial saliva was checked twice daily using a duly calibrated pH meter. The testing solution was buffered when changes in the pH were observed to maintain the required pH of this experiment.

Post-test SEM

Two samples each from G1A, G1B, G2A and G2B underwent SEM cross-sectional view at 2000x magnification. This was a randomized post-test of the samples to further investigate the samples tested.

Frictional force test

The samples were prepared for friction testing and each set underwent a pulling force test to simulate sliding mechanics. The arch wires were fixed on pre-adjusted brackets with a .022 slot (Roth prescription) using a 0.09 ss ligature wire that was twisted uniformly for five times across all samples. The samples were securely mounted to the universal testing machine with its crosshead pulling the archwire for 10mm at the speed of 1mm/6secs. A graph of applied force was plotted on the monitor screen and recorded in Newtons. A pull test using a Universal Testing Machine was applied to measure the coefficient of friction of the samples. This test required the use of special fixtures consisting of a sliding plane and a sled, which was performed on a material sliding over itself or on another type of surface as in the case of the bracket and arch wire in this experiment.

Bias

The possibility of an irregular coating of the arch wires is not impossible. To control this potential bias, the wires were coated uniformly by employing an automated spraying machine that ensures a uniform coating pressure and accurate coating and rest interval protocol on all surfaces of the samples.

Assumptions

It was assumed that all wires used in this experiment possess the same composition and mechanical properties. As well, it was presumed that the samples were coated evenly due to the fact that the same coating protocol was followed in all samples. Lastly, it was assumed that the GO solution was stored properly to prevent any alterations from the environment.

Data analysis

The data from the experiment was analyzed using SPSS software (version 23). Two-way ANOVA was used to compare the frictional force (dependent variable) of the uncoated and GO-coated wires (independent variables) soaked in different pH levels (5.5 and 6.8) of artificial saliva (independent variable), with a confidence interval of 95% with a p-value of <0.05.

RESULTS AND ANALYSIS

Sixty (60) samples were distributed into control and experimental groups. For control groups: G1A – 15 uncoated ss wires soaked in pH 5.5 artificial saliva, G1B – 15 uncoated ss wires soaked in pH 6.8 artificial saliva. For experimental groups: G2A – 15 GO-coated ss wires soaked in pH 5.5 artificial saliva, G2B – 15 GO-coated ss wires soaked in pH 6.8 artificial saliva. Two-way ANOVA was utilized to analyze the effect of pH on the frictional force of GO-coated stainless steel wire using a Universal Testing Machine.

SEM Results

The Figure 3, 4 Showing (Figure 3) SEM image of Stainless Steel (ss) with width of 0.017 inch and length of 0.025 inch magnified at 150x, 350x, and 1000x and (Figure 4) with Graphene Oxide (GO) coating before immersion in saliva.

Table 1: The mean and standard deviation of the control and experimental group samples.

pH	Groups	Mean	Std. Deviation	N
pH 5.5	Uncoated	1.49	0.28	15
	GO-Coated	1.43	0.22	15
	Total	1.46	0.25	30
pH 6.8	Uncoated	1.38	0.14	15
	GO-Coated	1.35	0.08	15
	Total	1.37	0.11	30

Table 1 presents the mean and standard deviation for the control and experimental groups (uncoated and GO-coated ss wires on pH 5.5 and 6.8). The mean of uncoated ss wires in pH 5.5 was 1.49±0.28 N (N=15), while the mean of the GO-coated ss wire in pH 5.5 was 1.43±0.22 N (N=15).

For the samples with pH 6.8, the mean of the uncoated ss wire was 1.38±0.14 N (N=15), while mean of GO-coated ss wire was 1.35±0.08 N (N=15).

Table 2: Test for normality of distribution between GO-coated and uncoated ss wires on frictional force (Shapiro-Wilk).

	Groups	Shapiro-Wilk		
		Statistic	df	Sig.
Friction	Uncoated	0.962	30	0.358
	GO-Coated	0.953	30	0.199

Table 2 is the normality test (Shapiro-Wilk), which indicates the normal distribution of data. Therefore, a parametric analysis of the data was used.

Table 3: Test for normality of distribution between pH groups (5.5 and 6.8) on friction (Shapiro-Wilk).

	pH Groups	Shapiro-Wilk		
		Statistic	df	Sig.
Friction	5.5	0.951	30	0.175
	6.8	0.960	30	0.310

Table 3 is the normality test (Shapiro-Wilk), which expresses the normal distribution of data. Therefore, a parametric analysis of the data was employed.

Table 4: Levene's test of the homogeneity of variances.

F	df1	df2	Sig.
6.791	3	56	0.001

Table 4 shows the Levene's test, to assess the homogeneity of variance. The equality of error variances was violated since the p≤0.05 (F=6.791, p=.001). Although this assumption was not satisfied, it did not present much of an issue statistically when groups have equal sample sizes since this situation makes the analysis robust to depart from the assumption of homoscedasticity or constant variances. According to Andy Field (2016), the assumption was pretty much irrelevant and could be ignored if the sample sizes are equal.

Table 5: Tests of Between-Subjects Effects (2-Way ANOVA).

Source	Type III Sum of Squares	D	Mean Square	F	Sig
Corrected Model	.158[a]	3	0.053	1.36	0.264
Intercept	120.163	1	120.163	3109.955	0
pH	0.126	1	0.126	0.756	0.076
Groups	0.029	1	0.29	3.268	0.388
pH*Groups	0.002	1	0.002	0.055	0.815
Error	2.164	56	0.039		
Total	122.484	60			
Corrected Total	2.321	59			

Table 5 tested the hypothesis and evaluated the effect of pH on frictional force of GO-coated stainless steel wires using a Universal Testing Machine. The result showed that there was no difference between the pH groups (5.5 and 6.8) on frictional force (F=.756, p=.076). Also, there was no difference between groups (GO-coated and uncoated ss wires) on frictional force (F=3.268, p=.388). Analysis of the result showed no interaction between the 2 independent variables (pH*groups) on frictional force (F= .055, p=.815).

Table 6: Estimated Marginal Means of GO-coated and uncoated ss wires and Ph.

Groups	pH	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Uncoated	pH 5.5	1.48	0.051	1.38	1.59
	pH 6.8	1.38	0.051	1.28	1.48
GO-coated	pH 5.5	1.43	0.051	1.33	1.53
	pH 6.8	1.35	0.051	1.25	1.45

Table 6 is the estimated marginal means of the uncoated ss wires and pH 5.5 was 1.48, uncoated pH 6.8 was 1.38. The estimated marginal means of the GO-coated ss wires and pH 5.5 was 1.43; uncoated pH 6.8 was 1.35.a

Table 7: Estimated Marginal Means of GO-coated and uncoated ss wires on friction.

Groups	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Uncoated	1.44	0.036	1.36	1.51
GO-coated	1.39	0.036	1.32	1.46

Table 7 is the estimated marginal means of the uncoated ss wires at 1.44 and for GO-coated ss wires at 1.39.

Table 8: Estimated Marginal Means between pH groups (5.5 and 6.8) on friction.

pH	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
pH 5.5	1.46	0.036	1.38	1.53
pH 6.8	1.36	0.036	1.29	1.44

Table 8 is the estimated marginal means of the pH 5.5 group on friction was 1.46 and estimated marginal means of the pH 6.8 group on friction was 1.36.

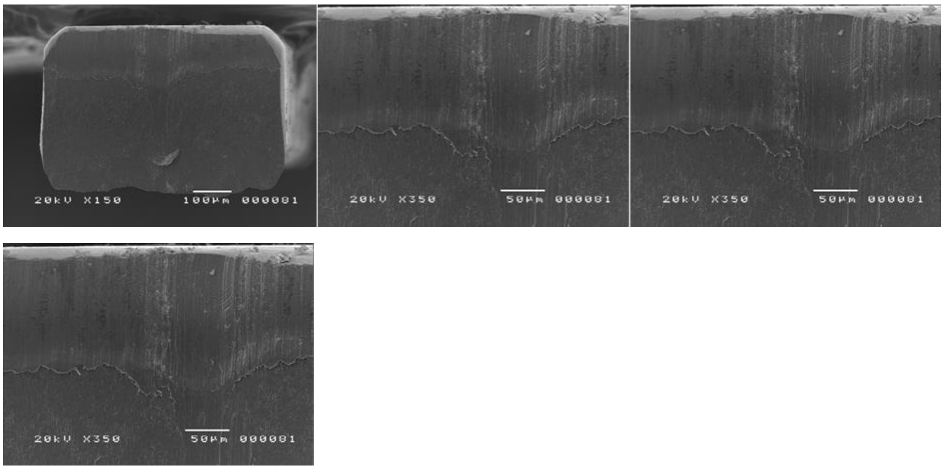

Figure 3: Uncoated stainless steel wire.

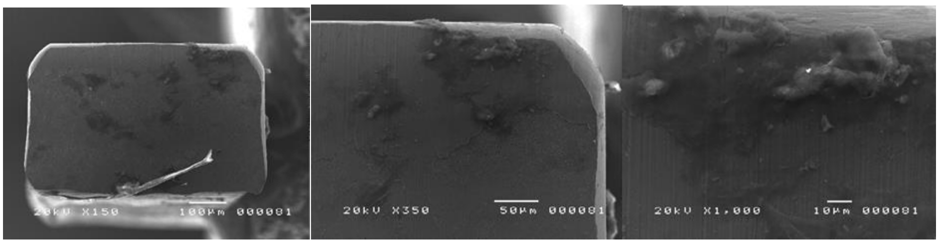

Figure 4: GO-coated stainless steel wire.

The Figure 3 shows the SEM image of stainless steel with width of 0.017 inch and length of 0.025 inch magnified at 150x, 350x, and 1000x before immersion in saliva excited with an electron beam of 20kV. The normal surface area of the stainless steel has an austenitic structure. The outer layer indicated that the material had undergone cold work and the center layer was mainly composed of the ferritic alloy.

The Figure 4 illustrates the deposited Graphene Oxide (GO) using the improvised spray method conducted by the researcher. The surface of the stainless steel was GO sprayed for 2 seconds, rest, then 5 seconds, rest, for 10 times. As shown in the SEM image, approximately GO particulates were randomly deposited in the ss surface with average size of 10 to 50 microns.

The Figure 5 shows the SEM image of ss (sample G1A) with similar width and length magnified at 150x, 350x, and 1000x immersed in artificial saliva for 24 hours 21 days with pH of 5.5. The magnified image showed the reactivity of the artificial saliva corroding the surface of the ss with length size of 169.23 microns.

The Figure 6 on the other hand, with similar conditions except for its pH 6.8 started to form corrosion of the outer layer of the ss (sample G1B). It had less surface reactivity since the corrosion occurred in random direction.

The Figure 7 shows the SEM image of GO-coated ss (sample G2A) with similar width and length magnified at 150x, 350x, and 1000x immersed in artificial saliva for 24 hours 21 days with pH of 5.5. The magnified image showed the reactivity of the artificial saliva corroding the surface of the ss with length size of 139.09 microns.

The Figure 8 on the other hand, with similar conditions except for its pH 6.8 started to form corrosion in the center of sample G2B with less surface reactivity since the corrosion occurred in random direction.

The Figure 9 shows the SEM image of ss (sample G1A) with similar conditions after undergoing UTM test. The frictional force applied is at 1.49 N which gave rise to 4 outer layer fractures with size 37.59 to 130.77 microns in the lower part of the sample G1A with a pressure of 3,505.88 Pa. On the other hand, Figure 10 exhibits 3 outer layer fractures with size 30.76 to 176.92 microns with an applied frictional force of 1.38N with a pressure of 3,247.06 Pa.

The Figure 11 shows the SEM image of ss (sample G2A) with similar conditions after undergoing UTM Test. The frictional force applied is at 1.43 N which gave rise to 1 outer layer fracture with size 30.77 microns in the lower part of the sample G2A with a pressure of 3,364.71 Pa. On the other hand, Figure 12 exhibited 0 outer layer fracture even with an applied frictional force of 1.35N and pressure of 3,176.47Pa.

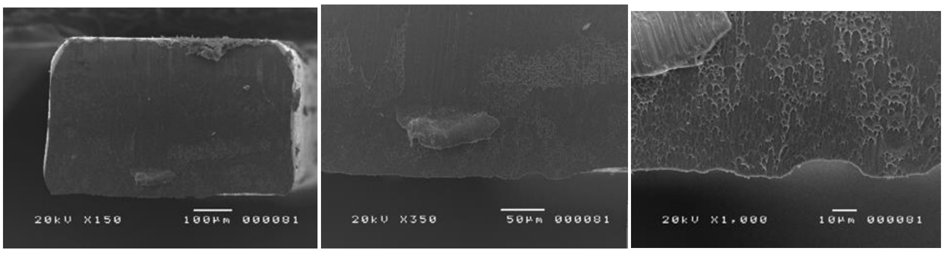

Figure 5: Stainless steel with immersed with artificial saliva with pH 5.5 (sample G1A).

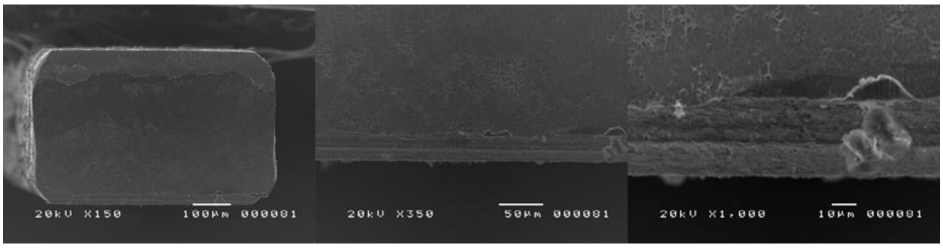

Figure 6: Stainless steel with pH 6.8 (sample G1B).

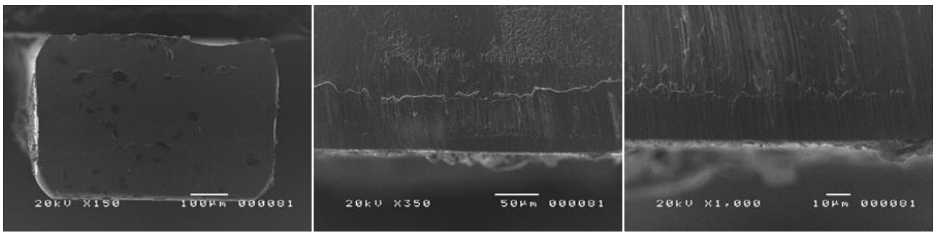

Figure 7: GO-coated with pH 5.5 (sample G2A).

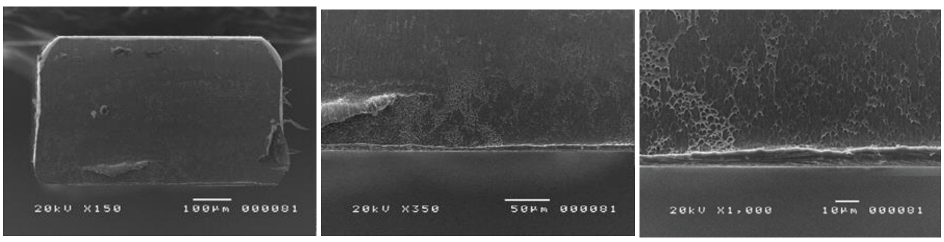

Figure 8: GO with pH 6.8 (sample G2B)

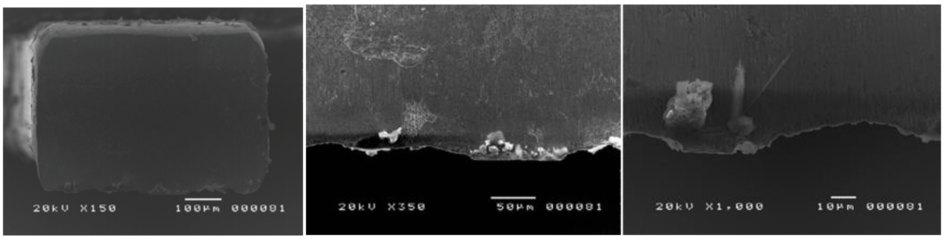

Figure 9: SEM image of ss (sample G1A) after UTM.

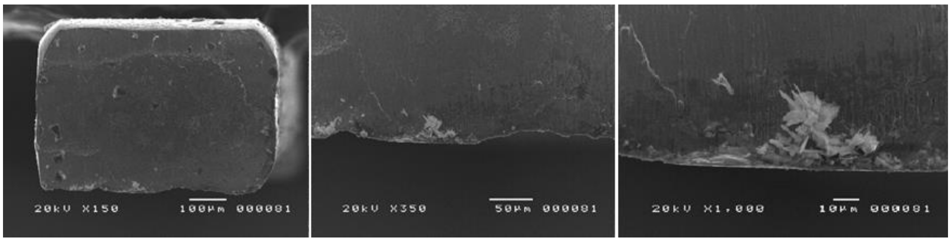

Figure 10: SEM image of ss (sample G2A) after UTM (G1B).

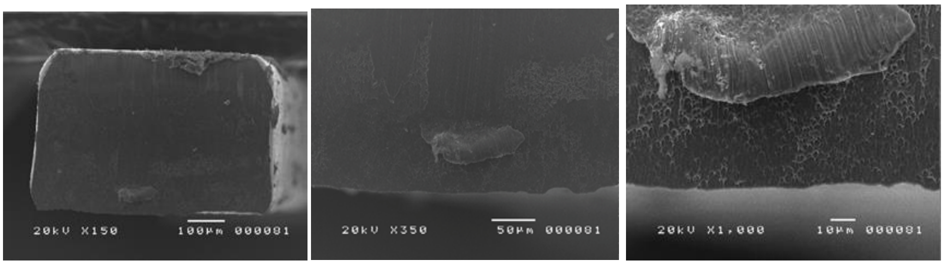

Figure 11: SEM image of GO (sample G2A) after UTM.

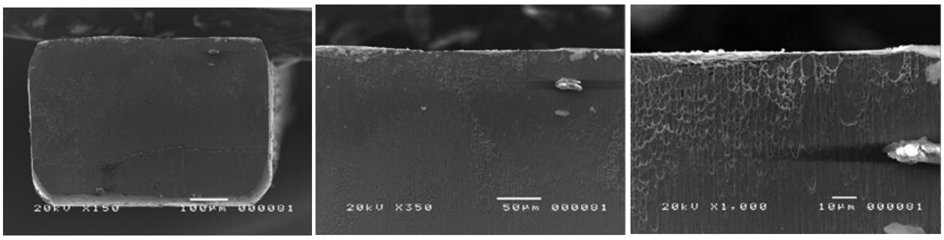

Figure 12: SEM image of GO (sample G2B) after UTM.

DISCUSSION

To a large extent, the outcome of orthodontic treatment relies on how well the forces are controlled and the resulting reactions. Sliding mechanics that involve friction are most frequently used in tooth movement, particularly during space closure. When frictional forces are strong, the effectiveness of tooth movement will be negatively affected and treatment time may be prolonged. The friction between arch wire and bracket is multifactorial in nature and can be divided basically into physical and/or biological factors hence, the current study was conducted. Graphene was also proven to be an effective corrosion barrier material because it was considered inert under the conditions where chemical reactions of other substrates will take place. With this, the aim of this study was to evaluate the effect of pH on frictional force of GO-coated stainless steel wires using friction test.

According to the results of the study, the mean frictional force of uncoated and GO-coated stainless steel wires was similar to each other. A possible reason for this would be that the experiment was done on a wet field, wherein, the samples were soaked in artificial saliva. This could have contributed to the lubrication of the wires, therefore, causing a similar frictional force between the uncoated and GO-coated wires.

In the current study, under SEM, uncoated stainless steel wires soaked in pH 5.5 exhibited more surface roughness as compared to GO-coated stainless steel wires. As well, the magnified image of the uncoated stainless steel wires showed reactivity of the artificial saliva, corroding the surface. Bigger surface irregularities were noted on the uncoated stainless steel wires soaked in pH 5.5. These findings corresponds with, which concluded that, with a lower pH, more roughness was found on stainless steel wires. Additionally, found bigger surface irregularities on stainless steel wires soaked in a more acidic artificial saliva (pH 5.5). They also concluded that pH played a synergistic effect on the change of mechanical properties of s wires. While GO-coated stainless steel wires showed less reactivity to the saliva, less corrosion was seen. A study done by proved that Graphene Oxide can be used as an inhibitory factor to wires from corrosion. Noted that coating decreases corrosion and coated arch wires can be used for patients allergic to nickel, when coatings are sustained. It also concurs with, which proposed that the wires coated with nanoparticles may offer a novel opportunity to substantially reduce friction during tooth movement. It must be noted that post SEM, presence of GO was still observed in the surface of the wires after friction force testing that potentially suggests its good adherence to the wire. These findings support the study of who also tested Graphene as a coating material. They found that Graphene was able to become a protective coating against scratch or other physical damage toward a substrate. The study also proved to be an effective corrosion barrier material because it was considered inert under the conditions where chemical reactions of other substrates take place. This exemplifies an improvement in the anti-corrosion property of a coating system.

CONCLUSION

The present study adopted an experimental design, using a post-test control group, to evaluate the friction force capability of GO-coated wires on different pH levels of artificial saliva. Based on the findings of this study, it may be concluded that there was no difference in the frictional force of uncoated and GO-coated stainless steel wires. As well, there was no interaction between the pH and wire groups (uncoated and GO-coated stainless steel wires) on frictional force. Thus, the hypothesis on the effect of pH on the frictional force on GO-coated stainless steel wires was rejected. GO-coated stainless steel wires may provide a low frictional force, which is imperative to orthodontic treatment for easier and faster tooth movement. Based on the images from the SEM, the GO coated stainless steel wires exhibited a smoother surface area and thus, may potentially provide a barrier for corrosion.

RECOMMENDATION

Coating stainless steel wires with GO will not alter the properties of the wire in terms of frictional force and pH resistance but it can be beneficial for its antimicrobial properties. Further study can be recommended by increasing the experiment time and/or exposure time to the test solutions. Comparison of different orthodontic arch wires (TMA, CNA, Australian stainless steel wires) should be assessed and a more sensitive test must be employed to investigate the topographical changes on the wire surface is also recommended.

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