ABSTRACT

Objective: To study the effect of prophylactic fluoride agents on the loading and unloading mechanical properties and surface quality of Stainless Steel orthodontic wires. Methods: SS wires were immersed in either an acidulated fluoride agent, Amine fluoride agent, Chlorhexidine or Artificial Saliva (control) for 1.5 hours at 37°C. After immersion, the loading and unloading elastic modulus and yield strength of the wires were measured using a 3-point bend test. A one-way analysis of variance and Turkey post hoc test were used to analyze the mechanical testing data. Scanning electron microscopy was also used to qualitatively evaluate the wire topography as a function of the fluoride treatments. Results: Unloading mechanical properties of SS wires were significantly decreased (P < .05) after exposure to both fluoride agents. Corrosive changes in surface topography were also observed after exposure to both the Amine and acidulated phosphate fluoride agents. Conclusions: The results suggest that using topical fluoride agents with SS wire could decrease the functional unloading mechanical properties of the wires and potentially contribute to prolonged orthodontic treatment.
KEYWORDS: SS Orthodontic wires, Surface characterization, mechanical properties Chlorhexidine; Fluoride prophylactic agents, Corrosion.

INTRODUCTION
Orthodontic arch wires are designed to move teeth with light continuous forces. Mechanotherapy depends on both the elastic behavior of the material and the biochemical reaction of the teeth. During the early years of our specialty, appliances were constructed mainly of precious metals. Since its introduction in the early 1956, stainless steel has proved to be a better material than alloys of precious metals for orthodontic appliances.

One of the most important components of successful orthodontic treatment is the maintenance of good oral hygiene and caries control. Compromised oral hygiene can lead to enamel demineralization and decay. Daily topical fluoride is commonly prescribed by orthodontists to guard against this complication. Acidulated phosphate fluorides (APFs) have been used extensively to prevent demineralization or remineralization of white spot lesions around orthodontic brackets. However, fluoride ions in the prophylactic agents have been reported to cause corrosion, discoloration and alteration of the mechanical properties of metallic wires, particularly when passivated wire surfaces break because of mechanical friction between brackets and wires.

Aim and Objectives: The present study intended to evaluate the effects of various fluoridated and Non-fluoridated prophylactic agents on the mechanical properties and surface topography of SS Orthodontic wires.

MATERIAL AND METHODS
Three types of commercially available mouthwashes Fluoridated (APF and Amine fluoride) and non- Fluoridated (Chlorhexidine) mouthwashes were used in this study. 19x25 SS (Orthoorganizer, USA) wire specimen were cut in 25mm in length. A total of 40 specimens were prepared and divided in to 4 groups. Ten specimens were incubated at 37°C in artificial Saliva (control treatment), and the other 30 specimen, 10 of each were incubated in fluoridated and non-fluoridated mouthwashes solution for 1.5 hours. This exposure time would be equivalent to 3 months of 1-minute daily topical fluoride applications. The fluoride agents were high fluoride-ion concentration gels; Phosflur mouthwash (1.1% acidulated phosphate fluoride, APF, 0.5% w/v fluoride, pH- 5.1; Colgate Oral Pharmaceuticals, Canton, Mass), Amine fluoride agents (Amflor mouthwash, pH-6.4, Group pharmaceuticals, Malur,
India) and Clohex plus mouthwash® (Chlorhexidine Gluconate 0.2% w/v, pH-7, Dr. Reddy’s).

Just before mechanical testing, the specimens were removed from their respective solutions, rinsed with distilled water and placed in new, clean, individually coded vials. Mechanical testing was based on the current American National Standard/American Dental Association Specification No. 32 for Orthodontic Wires. Each specimen was tested by using the 3-point bend test on a universal testing machine (model 4400R, Instron, Canton, Mass, Bluehill 2 software program (Version 2). The configuration of the 3-point fixture was a support span of 12 mm and 0.05-0.13 mm radii of each support and the striker. As indicated in the specification, the specimens were submerged and tested in a heated dH2O bath (37°C) to simulate the aqueous oral environment. Each specimen was loaded to a deflection of 3.1 mm and then unloaded to zero deflection at a cross-head speed of 1 mm/minute. Load, in newtons (N), and deflection, in millimeters (mm) were collected every 100 milliseconds or both loading and unloading of each specimen by using the Bluehill software program (version 2, Instron). Load-deflection curves were generated from these data; a representative load-deflection curve is shown in Engineering beam theory was used to calculate both modulus of elasticity (E) and Yield Strength (YS). The E for the loading and unloading slopes of each specimen was calculated by using the following equation: $E = \frac{L^3m}{4bd^3}$ (GPa), where L=support span (mm), b=width of specimen (mm), d -depth of specimen (mm), and m slope of the straight-line portion of the loaded or unloaded deflection curve (N/mm of deflection). YS was also determined from each loading and unloading portion of the curve.

The mechanical property data were analyzed by using a one way analysis of variance (ANOVA) for both the loading and unloading E and YS for each wire type. If there was a significant difference between groups, a turkey post-hoc test was used to determine which groups were significantly different from the control group. A p value of <0.05 was considered as statistically significant. After the mechanical testing, 3 representative specimens were selected from each wire/experimental condition group for scanning electron microscopy (SEM) analysis to qualitatively characterize the topography of the wire surface. The specimens were mounted with double-sided conductive carbon tape and carbon paint on aluminum SEM stubs and observed by using a machine (LEO 435VP, Model No: 7059, Made in England) at 15.0 kV. SEM photomicrographs were made at 1000x magnification. This qualitative analysis was applied to provide a potential link between the effect of fluoride
on the wire surface topography and any associated degradation of mechanical properties. One way ANOVA was used to analyze the significance of difference for mean MOE and YS (loading and unloading) between the experimental groups.

RESULTS
The results of the mechanical testing (Table 1) suggest, that the fluoride treatment produced a significant difference in both unloading modulus and the unloading YS of SS wire as compared with the Artificial saliva (control) treatment (P <0.05). In contrast, the Chlorhexidine did not produce any significant difference on Modulus of elasticity and YS.\textsuperscript{[11,12]} The 1-sided Turkey post-hoc test suggested that both fluoride mouthwash significantly decreased the SS wire unloading modulus and YS (Phosflur mouthwash P < 0.005; Amine fluoride mouthwash P < 0.005), while significant reduction on loading MOE and YS with Amine fluoride mouthwash when compared with other groups.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>TREATMENT</th>
<th>MODULUS OF ELASTICITY(GPa)</th>
<th>YIELD STRENGTH (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Loading*</td>
<td>Unloading*</td>
</tr>
<tr>
<td>1</td>
<td>Artificial saliva</td>
<td>147.45 ± 4.30</td>
<td>97.50 ± 3.21</td>
</tr>
<tr>
<td>2</td>
<td>Amine fluoride Mouthwash</td>
<td>144.41 ± 4.72</td>
<td>96.11 ± 2.08</td>
</tr>
<tr>
<td>3</td>
<td>Chlorhexidine Mouthwash</td>
<td>148.69 ± 3.20</td>
<td>97.45 ± 3.32</td>
</tr>
<tr>
<td>4</td>
<td>Acidulated phosphate fluoride Mouthwash</td>
<td>145.29 ± 4.44</td>
<td>95.32 ± 1.34</td>
</tr>
</tbody>
</table>

The wire surfaces exposed to control appeared to have numerous dark areas, which might be by-products of the manufacturing process that were not present after fluoride application. However, after APF application, in addition to no dark smudge areas, the wire surface also had a mottled, pitted appearance with increased appearance of bright-white spots, which appear to be inclusions in the wire that are revealed by the action of the fluoride agent. These effects of fluoride on the SS surfaces are demonstrated even more dramatically in the Amine fluoride specimen. The surface has elongated, globular, pitted defects, with even greater exposure of the white inclusions, indicating a more severe change in the wire surface topography as compared with the control. Chlorhexidine did produce much severe effect then compared to APF and Amine fluoride. Pitting appeared on the surface of the wire in both the Amine fluoride and APF mouthwash specimens. Both the Amine and APF mouthwash treated SS wires exhibited more discernible and distinct pitting than the similarly treated
Chlorhexidine mouthwash treated SS wires. Although wire color change was not part of the topographical analysis, only the fluoride-treated SS wires had a clinically observable darkening of the wire. In the current study, in addition to SS unloading mechanical property degradation after Amine fluoride, comparable mechanical property degradation followed exposure to APF exposure.

DISCUSSION
Topical fluorides are reported to cause corrosion of SS orthodontic wires, this suggests that fluoride might also adversely affect Stainless steel based alloy mechanical properties. In this study, two fluoridated (Amine fluoride and APF) and one non-fluoridated (Chlorhexidine) were used. Amflor treatment produced a statistically significant decrease in the Loading and unloading MOE and the unloading YS while the Phosflur produced the statically significant reduction in Unloading MOE and YS and Chlorhexidine did not produced any statically significant reduction when compared to Control Group. To date, there have been no other reported studies of the effect of amine fluoride agents on the loading and unloading mechanical properties of SS orthodontic wires.

The corrosion resistance Stainless steel wires depend on the formation of a passivation layer, an oxide film. Although the SS passivation layer is very complex, the protective character is due primarily to chromium oxide, Cr2O3. Surface passivation prevents further oxygen diffusion, resulting in corrosion resistance however, if the passivation layer is disrupted, the wires become susceptible to corrosion.13 Both Amine fluoride and APF Mouthwash produced qualitative surface topography changes on SS wires. Following fluoride exposure, Amine Fluoride treated wire exhibited an overall rougher surface, the cracks along the wrought structure were deeper and more accentuated when compared with APF treated wires. Chlorhexidine produced less severe surface topographic effect.

SS wire may interact with the HF acid that could be produced in the presence of acidulated fluoride. However, because of wire compositional differences, the SS alloy passive layer component might occur according to the following equation: Cr2O3 + 6HF → 2CrF3 + 3H2O.14,15 Similar to titanium-based alloys, once passive layer degradation occurs, SS alloy has a propensity for hydrogen absorption leading to embrittlement and stress corrosion cracking. Stress corrosion cracking of SS in the presence of fluoride has also been reported, an associated decrease in SS tensile strength following exposure to an acidulated fluoride solution (APF) was also reported.16,17
In the current study, in addition to SS unloading mechanical property degradation after Amine fluoride, comparable mechanical property degradation followed exposure to APF exposure. In addition to pH, the fluoride concentration could be an important factor in the breakdown of the alloy protective oxide layers, leading to potential hydrogen absorption and associated mechanical property changes. Accordingly, fluoride ion concentration would appear to be related to the SS wire mechanical property degradation associated with the Amine and APF agent in this study. Other previous fluoride wire mechanical property investigations have not examined loading and the more clinically relevant unloading properties. Instead, previous investigations have examined properties such as tensile strength at fracture. However, just as the decrease in wire tensile strength has been linked to hydrogen absorption following fluoride treatment, trapped interstitial hydrogen might be associated with the decrease in the unloading mechanical properties of SS wire after exposure to APF and Amine fluoride agents. It has been reported that absorbed hydrogen can be trapped within the SS lattice vacancies, potentially affecting both plastic flow and recovery. A similar situation might occur with hydrogen absorbed into the beta-Ti lattice structure. This explanation could help account for why only changes in unloading mechanical properties would be detected following fluoride exposure and potential associated hydrogen absorption. However, in order to confirm that phenomenon, future studies using hydrogen thermal analysis and x-ray diffractometry would be necessary. As with any in vitro investigation, the protocol cannot exactly simulate clinical conditions. The 1.5-hour fluoride exposure in this study attempted to simulate 3 months accumulation of 1-minute daily topical fluoride applications. In the clinical application, fluoride exposure would be repeated, shorter exposures with dilution of the fluoride with saliva. Therefore, a future study could address the effect of cumulative, shorter treatments and perhaps use the fluoride agents mixed in some measured ratio with an artificial saliva agent. Even though the reported decrease in SS Wire unloading mechanical properties may not seem large enough to be clinically significant, in spite of the limitations of replicating in vivo fluoride exposure, actual in vivo wire fluoride exposure could potentially be greater than that of the 3-month simulation. For instance, wires may remain in the oral cavity for 6 months or more while exposed to topical fluoride, fluoridated water and toothpaste, and fluoride-releasing bracket-bonding materials. Despite dilution with saliva, exposure time per 1-minute topical fluoride treatment may also be greater, because instructions indicate to avoid rinsing for at least 30 minutes after the application, in addition to recommending that the product be used before bedtime.
CONCLUSIONS

SS orthodontic wires exhibited qualitative surface topography changes following exposure to Amine or acidulated phosphate fluoride agents. After exposure to either Amine or acidulated prophylactic fluoride mouthwash SS wire showed a statistically significant decrease in unloading mechanical properties. Amine fluoride produced statically significant decrease in loading MOE also. Because unloading forces produce tooth movement, this decrease may be clinically relevant. Using topical fluorides with SS orthodontic wire might be a factor in prolonged orthodontic treatment time.

REFERENCES


