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Original Article

Corrosion Behavior of Nickel-Titanium Arch Wires Following the Use of Different Mouthwashes: An *In Vivo* Study

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Main Points

- Mouthwashes with different active agents are generally prescribed to orthodontic patients according to their special needs.
- Mouthwashes cause an increase in surface rougness of NiTi archwires
- Soft bristle toothbrush and aloe vera toothpaste may be suggested to orthodontic patients since they did not cause significant difference in surface roughness on NiTi archwires.

ABSTRACT

Objective: The aim of this double-blind *in vivo* study was to compare the extent of corrosion on the surface of nickel-titanium (NiTi) wires in various mouthwashes.

Methods: A total of 80 patients who received orthodontic treatment with as-received 0.016x0.022 inch NiTi wires were included in the study, and they were split into 4 groups. The first group used 0.05% of (225ppm F^-) sodium fluoride (NaF) (Colgate Plax®) containing mouthwash, 21.6% alcohol (Listerine Cool Mint®) containing mouthwash, and 0.2% clorhexidine (CHX) (Klorhex®) containing mouthwash and the control group used drinking water with melt menthol as mouthwash. After 30 days of using mouthwash, the surfaces of NiTi wires were examined with atomic force microscopy (AFM), and surface roughness values were calculated.

Results: Mouthwashes containing fluoride, essential oils, and CHX created higher surface roughness on NiTi wires than the control group. The floride-containing mouthwash group showed less corrosion than the CHX group, whereas there was no difference between the essential oil group. AFM images show supportive data with the results of the clinical study. The results were assessed using a 95% confidence interval and a significance level $p<0.05$.

Conclusion: CHX, essential oil, and floride-containing mouthwashes cause corrosion of NiTi wires. Floride-containing mouthwash can be preferred over CHX mouthwash due to its lesser corrosion effect.

Keywords: Corrosion, NiTi wires, CHX, essential oil, fluoride mouthwashes

INTRODUCTION

During orthodontic therapy, wires, brackets, and bands increase the areas for plaque retention and make it harder for patients to clean their teeth efficiently.[1] As a result, the oral flora alters, resulting in a higher risk of gingivitis and caries.[2] To prevent or treat gingival disease and tooth decay, clinicians generally prescribe mouthwashes containing different active agents in accordance with the patients' needs. These active agents

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include chlorhexidine (CHX), fluoride, and essential oils. Despite their frequent use, until now, only a few *in vitro* studies have evaluated the effects of fluoride[3-5] or CHX[6] and essential oils[7] on nickel-containing arch wires.

Previous *in vitro* studies have presented potential results and conclusions but they cannot provide certain statements because they cannot reliably mimic the oral environment. The oral environment contains a variety of substances, such as saliva and acids arising from the decomposition of food. This variable medium can alter the effects of mouthwash on nickel-titanium (NiTi) wires.

The purpose of the present study was to compare the corrosion effects of mouthwashes with different active agents, such as CHX, fluoride, and essential oil, on NiTi wires by measuring the changes in surface roughness of the wires after regular mouthwash use.

METHODS

The aim of this study was explained to the participants, and informed consent was obtained before the clinical trial (registration no.: 1067). The study was approved by the Clinical Research Ethics Committee of Yeditepe University (approval no.: 62/497, date: 26.06.2015).

Sample size was calculated using G*Power (version 3.1 Franz Foul, Universitat Kiel, Germany), and the effect size was calculated to be 0.40 with an alpha value of 0.05 and a power of 80%. A total of 80 subjects (43 females and 37 males) were included in this study. These patients were treated with fixed orthodontic treatment at the Department of Orthodontics, Yeditepe University. Orthodontic appliances consisted of an average of 4 tubes, 20 bonded brackets (Mini Master Series; American Orthodontics, Sheboygan, Wisconsin, USA), and NiTi wires (G&H® wire company, Greenwood, Indiana, USA).

One hundred and twenty patients were given nutrition forms and asked to list their daily diet for seven days before participating in the study. After one week, the dietary charts of each patient were evaluated for meal and each day. Patients with a convenient diet (non-acidic and sugary snacks and drinks) were included, while 40 patients who had acidic, sugary or starch-rich eating and drinking habits were eliminated from the study. During the study period, patients were informed to avoid acidic juice, ice tea, fizzy drinks, coffee, alcohol, chocolate, and sugary snacks.

Patients were randomly assigned to four study groups of 20 patients each. Randomization was achieved by assigning patients to different groups depending on their protocol number sequence. The first group used Colgate Plax [0.05% sodium fluoride (NaF) 225ppm F^-, pH: 6.9, Colgate-Palmolive Company, ABD], the second group used Listerine Cool Mint (%21.6 alcohol, pH: 4.1, Johnson & Johnson Healthcare Products Division of McNEIL-PPC, Inc, ABD), the third group used Klorhex (0.2% clorhexidine, pH: 5.5, Drogsan), and the fourth group, serving as the control group (CG), used a placebo with water, including melt menthol. Additionally, a fifth group was formed, which consisted of unused (as-received state) archwires. Patients were instructed to use mouthwash twice a day, 20 mL for 30 seconds after brushing their teeth. Standard equipment for brushing was provided to the patients. The toothpaste used was fluoride-free and aloe vera-containing [Forever Bright® (Forever Living Products, Scottsdale, AZ; 888.440.2563)], and the toothbrush was Colgate Slim Soft (Colgate-Palmolive Company, ABD) with thin and soft bristles to minimize the risk of creating surface roughness on the arch-wire while brushing.

In the upper arch 0.016x0.022 inch NiTi archwires were ligatured with elastomeric modules to prevent galvanic or fretting corrosion. The patients were instructed to brush their teeth with the provided equipment for three days before starting the use of mouthwash. After three days, the patients began using the mouthwashes as instructed for one month. Neither the participants nor the researcher knew which mouthwash was given for use in the double-blind experiment.

After one month of mouthwash use, the areas to be evaluated were marked using a diamond drill, before retrieving the arch-wire inter-bracket spaces. The retrieved wires were first cleaned under running water to remove fats and organic debris, then dried with air spray and soft paper. The retrieved archwires were placed in self-sealed envelopes, with the name of the patient and the code number of the mouthwashes recorded.

The three-dimensional surface roughnesses (R_a) of the archwires was examined using an atomic force microscopy (AFM, XE-100, PSIA Corp. Sungnam, Korea). The AFM images were obtained in non-contact mode using a cantilever (10M-NSC15, PSIA Inc.). The scan was performed at the surface with an average scanning speed of 0.5 Hz. Images with a scan size of 10 μm x 10 μm were obtained and analyzed using the XEI image processing program (version 1.8.0, Park Systems Corp. Suwon, Korea). The surface roughness of each wire was calculated by measuring and taking the average of the surface roughness values of three different regions (R_a).

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS Inc., Chicago Illinois, USA) for Windows 21.0 was used for data analysis. The average surface roughness values, namely the R_a values of the NiTi arch-wires, were compared using the one-way (ANOVA) test. Tukey's test was used for two-group comparisons.

RESULTS

Figure 1 shows the AFM analysis results for five different groups in the 3D images of the NiTi arch wires. After mouthwash use, the characteristic surface topographies were obvious for each group of NiTi arch wires. Greater surface roughness was evident for the CHX, alcohol or fluoride-containing mouthwash groups compared to the control and as-received groups. There was a statistically significant difference in the average surface roughness differences among the groups (Table 1, p=0.000, p<0.05).

Tukey's test analysis results (Table 2) showed that R_a value of fluoride-containing mouthwash group (FG) was statistically significantly different from that of the CHX-containing mouthwash group (CXG) (p=0.07), as well as the control, and as-received groups (p=0.00). Likewise, the control and as-received groups had statistically significant differences (p=0.00) compared to the alcohol-containing mouthwash group (AG). No significant difference was observed between the alcohol-containing mouthwash and the other commercial mouthwashes. Although a considerable difference in surface roughness values between AG and CXG was observed (-12.2 nm), this difference was not statistically significant (p=0.076).

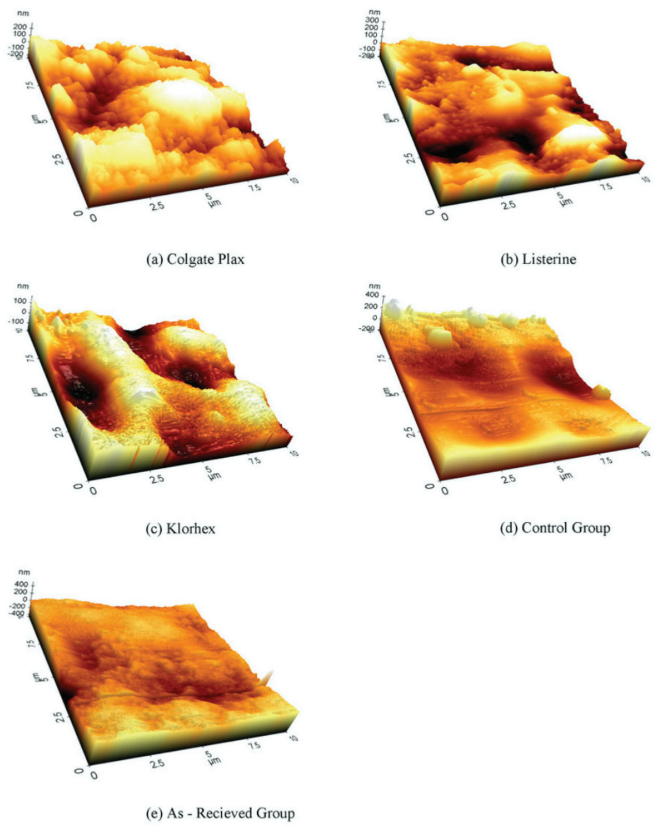

Figure 1. Atomic force three-dimensional reconstructed micrographs (10μm x 10μm)

Table 1. One-Way analysis of surface roughness differences of the NiTi arch-wires before (as-received) and after clinical mouthwash use

	Mean Ra (nm)	SD (±)	p value
Group 1 (Colgate Plax)	51.83	13.82	
Group 2 (Listerine)	55.78	24.02	
Group 3 (Klorhex)	67.98	16.47	**0.000***
Group 4 (control group)	30.47	6.77	
Group 5 (as-received)	19.37	1.42	

N: 20 Patients per group, Ra: Surface roughness (nanometer: nm), SD: Standard deviation, p<0.05

Discussion

In this *in vivo* study, the corrosion effects of different mouthwashes on NiTi wires were evaluated on the basis of previous *in vitro* studies.[3-7] For standardization, participants were selected based on nutritional forms supported by intraoral findings, which were expected to be free of erosion and abrasion that resembling a non-acidic oral environment.

Before using the mouthwash, our patients were instructed to have mouthwash free for 3 days, based on previous studies.[8,9] They brushed only with prescribed equipment to minimize the complexity of the intraoral environment, especially in reltion to previously used mouthwash and toothpaste ingredients, which may have contained active agents similar to those evaluated in this study. Aloe vera toothpaste was preferred because it does not contain any common active mouthwash ingredients and does not cause corrosion.[10]

The non-contact AFM technique was preferred for high-resolution AFM because it is non-destructive and the only mode capable of genuine atomic resolution. This technique not only allows imaging but also involves high-precision manipulation.[11]

Table 2. Tukey test analysis for statistical comparison of the groups

		p value
Group 1 (Colgate Plax)	Group 2 (Listerine)	0.915
	Group 3 (Klorhex)	**0.007***
	Group 4 (control group)	**0.000***
	Group 5 (as-received)	**0.000***
Group 2 (Listerine)	Group 1 (Colgate Plax)	0.915
	Group 3 (Klorhex)	0.076
	Group 4 (control group)	**0.000***
	Group 5 (as-received)	**0.000***
Group 3 (Klorhex)	Group 1 (Colgate Plax)	**0.007***
	Group 2 (Listerine)	0.076
	Group 4 (control group)	**0.000***
	Group 5 (as-received)	**0.000***
Group 4 (control group)	Group 1 (Colgate Plax)	**0.000***
	Group 2 (Listerine)	**0.000***
	Group 3 (Klorhex)	**0.000***
	Group 5 (as-received)	0.130
Group 5 (as-received)	Group 1 (Colgate Plax)	**0.000***
	Group 2 (Listerine)	**0.000***
	Group 3 (Klorhex)	**0.000***
	Group 4 (control group)	0.130

*p<0.05

The study design included 0.016 x 0.022 inch NiTi wires, which were easily stabilized during AFM measurements. Related to the evaluation of friction, it has been argued that tying a wire into the bracket creates a force and tension, making it difficult to objectively measure the tying force and maintain its constancy. These compression and tension areas may show fretting and galvanic corrosion. The reason to use a leveled arch was made to observe the effects of mouthwash corrosion while minimizing other types of corrosion.[12,13]

Since the frequency of the appointments for patients with fixed orthodontic appliances varies from 4 to 6 weeks, this study opted to investigate the arch wires after 1 month of clinical exposure and mouthwash use. In addition to reflecting regular appointment intervals, several studies have demonstrated that the levels of ion release caused by corrosion reaches peak level between 7 days[14] to four weeks.[15,16] Thus, the highest corrosion effects can be observed within this duration.

The present study identified a significant surface roughness increase, indicating more severe corrosion morphology on NiTi archwires during the use of all the commercial mouthwash, whereas the CG showed the lowest surface roughness value (Ra=30.47 nm). Since the CG used water as a mouthwash, the results of this group mimicked the effects of the oral environment on the NiTi arch-wires. Even if there was no statistically significant difference between the as-received and CG, a quantitative increase of 11.1 nm in the surface roughness of the arch wires was observed after a month of clinical exposure. This verifies that corrosion or a proteinaceous biofilm with a rougher surface, likely forming a calcified layer, developed on the wires,[11] Other similar studies have assessed the effects of the oral environment on NiTi wires using electron or optical microscopy and/or SEM.[17,18] Ghazal et al.[19] reported an increase of 25.74 nm in the surface roughness of NiTi wires after a month of clinical exposure. Unlike our results, this higher amount of surface roughness found in their study may result from the use of a different arch-wire brand, partial bonding of the dentition compared to full bonded patients in our study, the lack of standardized eating habits in their study compared to the standardized diet in the present study, and differences in oral hygiene equipment and disinfection procedures.

The comparison of the surface roughness of NiTi arch wires caused by mouthwashes revealed that CXG had higher values than FG, CG, and as-received archwires, but was not significantly different from AG. The pH of CHX-containing mouthwash (pH=5.5) was more acidic than that of fluoride-containing mouthwash (pH=6.9), yet it was less acidic than that of alcohol-containing mouthwash (pH=4.1). Although the pH values of CHX- and alcohol-containing mouthwashes had different levels of acidity, there was no statistically significant difference in surface roughness. Therefore, the greater amount of corrosion on the NiTi archwires may be attributed to the corrosiveness of CHX rather than its pH value. This finding is in accordance with studies in which CHX was used as an irrigation solution[20,21] and another study that compared different mouthwashes that cause ion release from orthodontic brackets.[21] On the other hand, the study by Nik et al.[22] reported that CHX did not affect the surface roughness of NiTi archwires, but their study was designed with an *in vitro* methodology, which did not precisely mimic the oral environment.

Titanium is an essential component of NiTi archwires, and CHX gluconate is an active ingredient in CHX-containing mouthwash. A complex interaction was observed between titanium and gluconate.[23,24] The titanium oxide (TiO_2) layer, which is a protective layer formed on archwires, can be increasingly dissolved in the presence of this complex reaction.[25]

It has been reported that at physiological pH, CHX is a highly positively charged molecule[26] with an affinity for negatively charged groups. During the formation of TiO_2 layer, multiple reactions and negatively charged molecules are involved. These unexpected electrochemical interactions can create a barrier to the maturation of TiO_2 layer. This prolonged or inhibited formation of the TiO_2 layer may explain the greater corrosion of NiTi wires in the presence of clorhexidine.

In our study, the NiTi arch-wires in the AG and FG exhibited significantly high surface roughness values. The only study that evaluated and compared the corrosion resistance of nickel-containing orthodontic arch-wires against alcohol-containing mouthwash showed that the Cr-Ni alloy exhibited the highest corrosion resistance in alcohol-containing mouthwash compared to Hank's solution and sodium fluoride containing mouthwash.[7] This opposite finding could be due to different factors, such as differences in the composition of the archwire, *in vitro* methodology, examination technique, and constant temperature. The corrosion rate of different types of NiTi archwires has been shown to increase with temperature.[27] Bhola et al.[28] evaluated the effect of alcohol-containing mouthwash on implants and reported corrosion of Ti6Al4V alloys. Our finding are in accordance with Bhola's study[25,28] and the induction of corrosion by alcohol-containing mouthwash on NiTi archwires. Alcohol-containing mouthwash contains ingredients such as essential oils, alcohol (ethanol) and it has an acidic pH of 4.1. It has been reported that with decreasing pH, the ethanol absorption of TiO_2 increases.[29] These cumulative factors and possible reactions could explain the protective TiO_2 degradation and corrosion observed in AG.

The corrosion observed in FG was statistically higher than that in the as-received group and lower than that in the CXG group, yet there was no significant difference compared to the AG group. Although the pH of the sodium fluoride-containing mouthwash (pH=6.9) was higher, the average corrosion observed on NiTi wires was similar to that in the AG group. These results might be attributed to the presence of fluoride ions. Earlier *in vitro* studies[5,30,31] have shown that fluoride-containing mouthwashes (250 ppm) can cause corrosion on NiTi arch-wires. Because our study design was *in vivo*, interactions within the oral environment should be considered, as they may affect the extent of corrosion.

Carbohydrate metabolism by bacteria in the oral cavity, results in the formation of acetic acid.[32] When acetic acid is formed, it reacts with fluoride to produce hydrofluoric acid (HF). Higher concentrations of fluoride ions in the oral cavity result in more HF. HF reacts with TiO_2, dissolving the protective TiO_2 layer by forming TiO_2 fluoride or titanium fluoride.[33,34] The degradation of the protective layer results in the exposure of the underlying alloy and rapid corrosion. In our study, the TiO_2 layer was most likely destroyed in this manner, as shown in the Table 3.[35]

Table 3. Titanium oxide layer reactions in the presence of hydrofluoric acid[35]

$Ti_2O_3 + 6HF \rightarrow 2TiF_3 + 3H_2O$
$TiO_2 + 4HF \rightarrow TiF_4 + 2H_2O$
$TiO_2 + 2HF \rightarrow TiOF_2 + H_2O$

TiO_2: Titanium oxide, HF: Hydrofluoric acid

Corrosion causes pit defects on archwires, which create suitable areas for plaque accumulation. Since a rougher surface results in more friction between brackets and wires, we believe that the success of orthodontic treatment could be negatively affected.

Study Limitations

A limitation of the present study was the standardization of the oral environment, which is complex and contains variables. In future studies, careful consideration should be given to standardizing solid variables that affect the amount of corrosion, such as crowding, wire type, ligation technique, and oral hygiene practices.

CONCLUSION

All mouthwashes containing different active agents created corrosion on the surface topography of the NiTi archwires.

Floride-containing mouthwash can be preferred over CHX mouthwash due to its lesser corrosion effect.

The changes in the NiTi archwires caused by the oral environment were not statistically different from the as-received wires.

Ethics

Ethics Committee Approval: The study was approved by the Clinical Research Ethics Committee of Yeditepe University (approval no.: 62/497, date: 26.06.2015).

Informed Consent: The aim of this study was explained to the participants, and an informed consent form was obtained before the clinical trial.

Author Contributions: Surgical and Medical Practices - Concept - Design - Data Collection and/or Processing - Analysis and/or Interpretation - Literature Review - Writing - All authors contributed equally.

Declaration of Interests: All authors declare that they have no conflict of interest.

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References

1. Schwaninger B, Vickers-Schwaninger N. Developing an effective oral hygiene program for the orthodontic patient: review, rationale, and recommendations. *Am J Orthod*. 1979;75(4):447-452. [CrossRef]
2. Sinclair PM, Berry CW, Bennett CL, Israelson H. Changes in gingiva and gingival flora with bonding and banding. *Angle Orthod*. 1987;57(4):271-278. [CrossRef]
3. Abalos C, Paúl A, Mendoza A, Solano E, Gil FJ. Influence of topographical features on the fluoride corrosion of Ni-Ti orthodontic archwires. *J Mater Sci Mater Med*. 2011;22(12):2813-2821. [CrossRef]
4. Huang HH. Variation in surface topography of different NiTi orthodontic archwires in various commercial fluoride-containing environments. *Dent Mater*. 2007;23(1):24-33. [CrossRef]
5. Schiff N, Grosgogeat B, Lissac M, Dalard F. Influence of fluoridated mouthwashes on corrosion resistance of orthodontics wires. *Biomaterials*. 2004;25(19):4535-4542. [CrossRef]
6. Brar AS, Singla A, Mahajan V, Jaj HS, Seth V, Negi P. Reliability of organic mouthwashes over inorganic mouthwashes in the assessment of corrosion resistance of NiTi arch wires. *Journal of Indian Orthodontic Society*. 2015;49(3):129-133. [CrossRef]
7. Cestarolli DT, Alves VA, Da Silva LA. In situ and ex situ characterization of a Fe-Cr-Ni alloy in mouthwashes and Hank's solution. *Chemical Papers*. 2008;62(3):326-328. [CrossRef]
8. Marchetti E, Mummolo S, Di Mattia J, et al. Efficacy of essential oil mouthwash with and without alcohol: a 3-day plaque accumulation model. *Trials*. 2011;12:262. [CrossRef]
9. Versteeg PA, Rosema NA, Hoenderdos NL, Slot DE, Van der Weijden GA. The plaque inhibitory effect of a CPC mouthrinse in a 3-day plaque accumulation model - a cross-over study. *Int J Dent Hyg*. 2010;8(4):269-275. [CrossRef]
10. De Oliveira SMA, Torres TC, Pereira SLDS, Mota OMDL, Carlos MX. Effect of a dentifrice containing Aloe vera on plaque and gingivitis control. A double-blind clinical study in humans. *J Appl Oral Sci*. 2008;16(4):293-296. [CrossRef]
11. Lauritsen JV, Reichling M. Atomic resolution non-contact atomic force microscopy of clean metal oxide surfaces. *J Phys Condens Matter*. 2010;22(26):263001. [CrossRef]
12. Clocheret K, Willems G, Carels C, Celis JP. Dynamic frictional behaviour of orthodontic archwires and brackets. *Eur J Orthod*. 2004;26(2):163-170. [CrossRef]
13. Eliades T, Zinelis S, Papadopoulos MA, Eliades G, Athanasiou AE. Nickel content of as-received and retrieved NiTi and stainless steel archwires: assessing the nickel release hypothesis. *Angle Orthod*. 2004;74(2):151-154. [CrossRef]
14. Kuhta M, Pavlin D, Slaj M, Varga S, Lapter-Varga M, Slaj M. Type of archwire and level of acidity: effects on the release of metal ions from orthodontic appliances. *Angle Orthod*. 2009;79(1):102-110. [CrossRef]
15. Park HY, Shearer TR. In vitro release of nickel and chromium from simulated orthodontic appliances. *Am J Orthod*. 1983;84(2):156-159. [CrossRef]
16. Ağaoğlu G, Arun T, Izgi B, Yarat A. Nickel and chromium levels in the saliva and serum of patients with fixed orthodontic appliances. *Angle Orthod*. 2001;71(5):375-379. [CrossRef]

17. Eliades T, Eliades G, Athanasiou AE, Bradley TG. Surface characterization of retrieved NiTi orthodontic archwires. *Eur J Orthod*. 2000;22(3):317-326. [CrossRef]

18. Petoumeno E, Kislyuk M, Hoederath H, Keilig L, Bourauel C, Jäger A. Corrosion susceptibility and nickel release of nickel titanium wires during clinical application. *J Orofac Orthop*. 2008;69(6):411-423. [CrossRef]

19. Ghazal ARA, Hajeer MY, Al-Sabbagh R, Alghoraibi I, Aldiry A. An evaluation of two types of nickel-titanium wires in terms of micromorphology and nickel ions' release following oral environment exposure. *Prog Orthod*. 2015;16(1):9. [CrossRef]

20. Dartar Öztan M, Akman AA, Zaimoglu L, Bilgiç S. Corrosion rates of stainless-steel files in different irrigating solutions. *Int Endod J*. 2002;35(8):655-659. [CrossRef]

21. Danaei SM, Safavi A, Roeinpeikar SMM, Oshagh M, Iranpour S, Omidekhoda M. Ion release from orthodontic brackets in 3 mouthwashes: an in-vitro study. *Am J Orthod Dentofacial Orthop*. 2011;139(6):730-734. [CrossRef]

22. Nik TH, Hooshmand T, Farazdaghi H, Mehrabi A, Razavi ESE. Effect of chlorhexidine-containing prophylactic agent on the surface characterization and frictional resistance between orthodontic brackets and archwires: an in vitro study. *Prog Orthod*. 2013;14(1):48. [CrossRef]

23. Mude N, Chokhani D, Kharche A, Khudare P, Joteppa V, Mohani S. Changes in the force degradation of orthodontic elastomeric chains subjected to different formulations of chlorhexidine mouth rinse: An in vitro study. IJHS. 2022;6(S1):12572-12585. [CrossRef]

24. Sufarnap E, Harahap KI, Adiana ID, Lim D, Lim C, Christy C. Corrosion of copper nickel titanium archwire in chlorhexidine, sodium fluoride, and chitosan mouthwashes. *F1000Res*. 2024;12:159. [CrossRef]

25. Bhola SM, Kundu S, Alabbas F, Mishra B, Olson DL. An electrochemical study on chlorhexidine gluconate addition to normal saline for oral implant applications. *Int J Electrochem Sci*. 2013;8(4):5172-5182. [CrossRef]

26. Helms JA, Della-Fera MA, Mott AE, Frank ME. Effects of chlorhexidine on human taste perception. *Arch Oral Biol*. 1995;40(10):913-920. [CrossRef]

27. Pun DK, Berzins DW. Corrosion behavior of shape memory, superelastic, and nonsuperelastic nickel-titanium-based orthodontic wires at various temperatures. *Dent Mater*. 2008;24(2):221-227. [CrossRef]

28. Bhola R, Chandra C, Alabbas FM, Kundu S, Mishra B, Olson DL. Corrosion response of Ti6Al4V and Ti15Mo dental implant alloys in the presence of listerine oral rinse. *International Journal of Corrosion*. 2013;2013(1):1-7. [CrossRef]

29. Ngadi N, Jamaludin SK. Effects of pH on ethanol photocatalytic oxidation using TiO_2 and zeolite 13X as catalyst. *J Teknol*. 2005;43(C):27-38. [CrossRef]

30. Schiff N, Boinet M, Morgon L, Lissac M, Dalard F, Grosgogeat B. Galvanic corrosion between orthodontic wires and brackets in fluoride mouthwashes. *Eur J Orthod*. 2006;28(3):298-304. [CrossRef]

31. Mammadov İ. *Evaluation of effects of prophylactic fluoride solutions on surface changes and ion release of titanium based orthodontic wires. Istanbul University*; 2010. [CrossRef]

32. Loesche WJ. Role of Streptococcus mutans in human dental decay. *Microbiol Rev*. 1986;50(4):353-380. [CrossRef]

33. Oda Y KEYMHKOT. The influence of fluoride concentration on the corrosion of titanium and titanium alloys. . Japanese Society for Dental Materials And Devices. 1996;6:283-288. [CrossRef]

34. Boere G. Influence of fluoride on titanium in an acidic environment measured by polarization resistance technique. *J Appl Biomater*. 1995;6(4):283-288. [CrossRef]

35. Watanabe I, Watanabe E. Surface changes induced by fluoride prophylactic agents on titanium-based orthodontic wires. *Am J Orthod Dentofacial Orthop*. 2003;123(6):653-656. [CrossRef]