REVIEW ARTICLE

Effect of Fluoridated Mouthwashes on Corrosion Property of Orthodontic Appliances: A Narrative Review

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Abstract

Objective: To analyze the effects of various fluoride agents on metallic orthodontic materials.

Design: PubMed, Google Scholar, and Embase were searched using keyword combinations such as fluoride mouthwash and orthodontic appliance and corrosion, fluoride and fixed appliance, and metal degradation.

Results: Of 315 articles, 20 were selected for inclusion in the review. All types of fluoride agents, especially the acidulated form of fluoride, seemed to influence the corrosion of orthodontic metallic appliances.

Conclusion: Since most of the studies reported suggest that fluoride ions are capable of causing corrosion of metallic orthodontic appliances, attention should be paid while prescribing fluoride agents for orthodontic patients. The degree of corrosion seems to be directly correlated with the acidity of the medium and the concentration of fluoride ions. Co-Cr brackets are resistant to corrosion by fluoride while stainless steel and Ti brackets are susceptible.

Clinical significance: It allows making the right choice while choosing the orthodontic brackets in relation to their susceptibility to corrosion by fluoride ions.

Keywords: Corrosion, Fluoride mouthwash, Orthodontic appliance, Susceptibility.

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Background

Corrosion refers to the conversion of a refined metal into a stable form as oxides, hydroxides, carbonates, or sulfides. The Glossary of Prosthodontic Terms (GPT) defines it as “a deterioration of a metal as a result of an electrochemical reaction within its environment or to eat away by degrees as if by gnawing or to wear away gradually, usually by chemical action.” Corrosion of orthodontic appliances is an important consideration since the corrosion products may cause localized or systemic toxicity of the body or affect the properties and clinical performance of appliances.[1]

Barrett et al. hypothesized that the acid pH, enzymes in saliva, acids, and microflora provide an oral environment that favors corrosion.[2] Corrosion resistance is critical for orthodontics since corrosion can lead to surface roughness and reduction in strength of appliances leading to their mechanical failure and leaching of ions from the alloy which may produce discoloration and/or allergic reactions in adjacent mucosae, and increased frictional forces.[3]

Orthodontic wires form a passive oxide film that resists corrosion; this is susceptible to both chemical and mechanical disruption. However, even without disruption, the oxide layer slowly dissolves in what is called passivation. Chloride and fluoride ions and acidic conditions can accelerate the passivation process. Fluoride-based mouthwashes also contribute to an acidic condition which increases the susceptibility of metals to corrosion.[4] Fluoride mouthwashes are routinely prescribed for patients undergoing orthodontic treatment to prevent white spot lesions. The use of fluoride agents promotes remineralization and prevents the development of incipient dental caries. The weekly use of 0.2% NaF mouthwash, added to existing oral hygiene protocol, improved DMFT scores in students (where community water was below 0.7 ppm fluoride) by 51.5% when compared to the control.[5] White spot lesions (WSL) are generally seen in and around the bracket due

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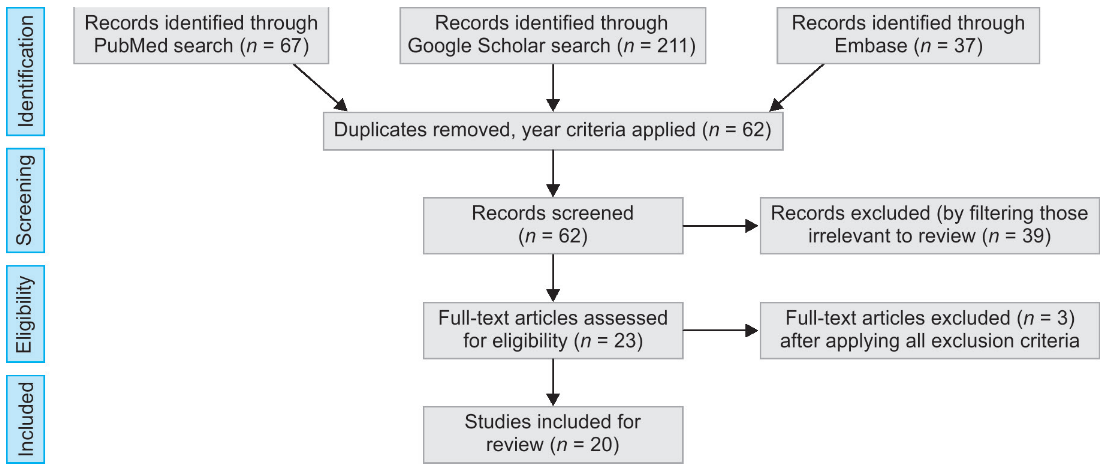
Flowchart 1: Study selection based on PRISMA guidelines (2009)



to adherence to food particles and improper oral hygiene. These are the areas of decalcification caused by bacterial flora persisting on enamel surfaces.[5] Adhesives around orthodontic attachments constitute retention of bacterial colonies.[6] Studies find an alteration in plaque profile when orthodontic appliances are placed, with higher concentrations of acidogenic bacteria like *Streptococcus mutans* and *Lactobacillus*. Along with retained carbohydrates, the attainment of the critical pH results in demineralization.[7] Fluoridated mouthrinses induce the formation of fluorapatite and fluor-hydroxyapatite in the enamel which are resistant to acid attacks and perform as caries preventive agents.[7,8]

There has not been a clear concise regarding the effect of fluoride agents on metallic orthodontic materials with regard to corrosion. This is of interest given the ability of fluoride ions in accelerating the passivation process of metals.[4] This review aims to analyze the orthodontic literature on the effects of fluoride agents used as mouthrinses, toothpaste, or varnishes on orthodontic materials with respect to their corrosion properties.

Materials and Methods

Sources, Search, and Study Selection

We searched the online literature in major databases including PubMed, Google Scholar, and Embase. The search was carried out between January 1980 and December 2021. The keywords for the search included "fluoride mouth rinse" OR "fluoride mouth wash" OR "fluoride*" (Mesh Term) AND "orthodontic appliance" (Mesh Term) OR "fixed appliance" (Mesh Term) OR "orthodontic*" AND "corrosion" (Mesh Term) OR "corrosive" OR "metal dissolution" OR "metal degradation." The selection was based on inclusion and exclusion criteria. We employed the PRISMA guidelines for this process.

Inclusion Criteria

- Articles studying the corrosion effects on orthodontic materials by fluoride ions
- *In vitro* studies from 1980 to 2021
- Use of conventional fluoride solutions/pastes normally used by patients
- Use of artificial saliva medium
- Metallic orthodontic appliances

Exclusion Criteria

- Articles studying other effects than corrosion on orthodontic materials by fluoride ions
- *In vivo* and human/animal studies
- Nonorthodonticic metallic appliances
- Nonmetallic orthodontic appliances

Data Collection

A customized data form was prepared which included the Author Name/Year of publication, Study design/Methodology, samples and groups tested, the fluoride agent used, the methodology used to test corrosion resistance, and their inferences. To eliminate subjective bias, two independent observers were employed to study the articles and fill out the forms. The final form was based on consensus opinion.

Data Analysis

The authors performed a qualitative analysis based on the information obtained from the customized data collection forms. The focus was on the type/part of the appliance (wire, bracket, and fixed retainer), the metal/alloy composition, the type of exogenous fluoride with fluoride concentration and pH, and the surface corrosion characteristics as identified by various methods (SEM, atomic force microscopy, voltammetry, plasma mass spectroscopy, electrochemical analysis, energy dispersive spectroscopy, and universal testing machine).

Final Analysis and Qualitative Synthesis

The authors assessed the final selected studies with the objective of determining the type of fluoride agent, the fluoride concentration, and pH that is associated with the highest (and lowest) corrosion levels; the orthodontic material that is most (and least) susceptible to fluoride-induced corrosion. A critical analysis of the articles was also performed to determine their strengths and limitations and to highlight possible biases.

Results

The searches revealed a total of 315 articles. There were 211 articles in Google Scholar search, 67 publications in PubMed, and 37 in Embase. Of these 62 were selected after eliminating duplications. These 62 were screened with their abstract and 39 were eliminated based on the stepwise application of the inclusion and exclusion criteria mentioned in the earlier section. The remaining 23 were scrutinized further and 3 were eliminated since they were animal studies. Twenty[9] relevant and scientifically sound studies were selected for inclusion in the review (Flowchart 1).

Description of Studies

All the studies selected were *in vitro* and done in an artificial saliva medium. One study was *in vivo* type. Table 1 summarizes the effect of fluoride on orthodontic materials.

Materials Tested

The materials tested included NiTi arch wires in 18 studies:[3,10–22] stainless steel arch wires in seven studies,[3,11,13,15,19,21,23] titanium alloys in four studies,[3,12,16,24] and cobalt chromium in two studies.[13,14]

Forms of Materials

Different materials were used in the form of brackets,[18,25] archwires,[10–13,16–22,26–28] both uncoated, coated, and ion implanted, and retainers.[29]

Forms of Fluoride Used

Fluoridated artificial saliva in three studies,[10,11,29] fluoridated mouthwash/rinse like Elmex, Meridol, and Acorea in four studies,[12,13,16,30] fluoridated toothpaste in four studies,[3,13,15,24] and fluoride gel in

Table 1: Summarizes the effect of fluoride on orthodontic materials

Sl. No.	*Author name/ year of publication*	*Study design*	*Samples and groups*	*Fluoride agent used*	*Surface corrosion resistance assessment*	*Results and inference*
1.	Perinetti et al., 2012[10]	*In vitro*	Compared 2 types of NiTi archwire (55 each) (Thermaloy®, NeoSentalloy)	1500 ppm F in artificial saliva	Scanning electron microscopy (SEM) Atomic force microscopy, (AFM), a universal testing machine for ultimate tensile strength	Different NiTi-based archwires can show different corrosion resistance. Thermocycling has no effects on the surface corrosion and fracture resistance of NiTi-based archwires.
2.	Heravi et al., 2014[11]	*In vitro* study	Three types of NiTi archwires, (Dentaurum, Global, and GAC), and SS archwire	Artificial saliva containing 0.05 wt% and 0.2 wt% sodium fluoride	SEM	The NiTi wires experienced deterioration of their corrosion properties under the effect of fluoride but not as much as the stainless steel archwires
3.	Schiff et al., 2005[3]	*In vitro*	TMA, NiTi TiNb, CuNiTi	Three fluoride mouthwashes: Elmex pH 4.3. Meridol pH 4.2. Acoreas pH 4.5	Corrosion resistance analysis by voltammetry and surface analysis by Scanning electron microscope	Elmex mouthwash for patients with TMA and NiTi-based orthodontics wires and Acorea or Meridol mouthwashes for patients with TiNb orthodontics wires.
4.	Yanisarapan et al., 2018[14]	*In vitro*	Brackets with tubes ligated with SS, NiTi, Beta-Ti	Fluoridated toothpaste, APF	Corrosion resistance was assessed by plasma-atomic emission spectrometry (ICP-MS) and surface analysis by SEM	SEM of APF groups showed higher signs of corrosion
5.	Schiff et al., 2006[16]	*In vitro*	Nickel-titanium (NiTi) and copper-nickel-titanium (CuNiTi) wires and, titanium (Ti), iron-chromium-nickel (FeCrNi) and cobalt-chromium (CoCr) brackets	Two commercially available fluorides (250 ppm) mouthwashes, Elmex and Meridol	Corrosion test—ICP-MS, SEM	Mouthwashes should be prescribed according to the orthodontic materials used
6.	Schiff, 2005[16]	*In vitro*	Brackets: CoCr, FeCrNi Titanium compared with platinum (Pt)	Elmex, Meridol, and Acorea mouthwashes	Corrosion resistance analysis by voltammetry and surface analysis by scanning electron microscope	Because of the risk of corrosion Meridol® mouthwash should not be prescribed for patients wearing Ti or FeCrNi-based orthodontic brackets
7.	Katic, 2018[30]	*In vitro*	Uncoated NiTi, nitride coated NiTi, and rhodium (RhNiTi)-coated NiTi archwires	Topical fluoride gels: Elmex gelée, Mirafluor-k-gel, MI Paste Plus	Electrochemical impedance spectroscopy (EIS) and cyclic polarization	uNITI and NNiti corrosion resistance decreases with high concentration of HF rhNITI corrosion resistance decreases on continuous exposure of low HF concn but at high HF concentration corrosion resistance increases

8.	Pulikkottil et al., 2016[13]	*In vitro*	Archwires made of SS, NiTi, Ti Mb (TMA), and ion-implanted TMA	NaF concentrations of 0% and 0.5% (similar to high fluoride-toothpaste of 2250 ppm)	SEM, energy dispersive spectroscopy. AFM, linear polarization test	Corrosion resistance is high in low-friction TMA and lowest in SS. Surface roughness is lowest in TMA and high in SS. 0.5% acidic fluoride-containing artificial saliva was the most corrosive
9.	Simindinger, 2021[29]	*In vitro*	Lingually bonded retainer	Fusayama-Meyer plus fluoride similar to the Fluoride concentration of toothpaste	Three-hour open circuit potential (OCP) measurement, polarization resistance (Rp), corrosion current (Icorr)	Twisted wires experience significantly greater corrosion rates than solid wires of the same. Gold plating protects against corrosion. Fluoride increases the susceptibility of most wires to corrosion.
10.	Chantarawaratit et al., 2021[15]	*In vitro*	Stainless steel brackets along with three different archwires-SS, NiTi, TMA	Fluoridated toothpaste, 1.23% APF gel	Plasma mass spectroscopy for electrochemical, SEM for surface roughness, cytotoxicity test for gingival cells	Used brackets significantly prone to corrosion. Acidulated phosphate fluoride (APF) gel is contraindicated in patients with fixed metal appliances.
11.	Iijima et al., 2010[26]	*In vitro*	Ion implanted NiTi wire (Neo Sentalloy longuard) Non ion implanted NiTi wire (Neo Sentalloy) as control	Butler F Mouthrinse 0.1% (NaF, 500 ppm and pH 6, and Ora-Bliss mouth-rinse (NaF (450, 900 ppm F)	Potentiodynamic polarization measurement and surface morphology with SEM	Corrosion potential was comparable in both types but non ion implanted NiTi wire had a higher breakdown potential
12.	Fais et al., 2012[24]	*In vitro*	Commercially pure titanium and Ti–6Al–4V disks	Deionized water (W), fluoride-free toothpaste (T), and fluoride toothpaste (FT)	Surface topography using atomic force microscope, scanning electron microscope with energy-dispersive X-ray spectroscopy (EDS)	Exposure to toothpaste (immersion) does not affect titanium *per se*; their use during brushing affects titanium topography and roughness. The associated effects of toothpaste abrasives and fluorides seem to increase roughness on titanium brushed surfaces.
13.	Ramalingam et al., 2008[17]	*In vivo* study	NiTi and copper NiTi archwires	Fluoride rinse, fluoride gel	Surface analysis with scanning electron microscopy, moduli of elasticity, and yield strengths	Topical fluoride agents alter the mechanical properties of NiTi wires
14.	Walker et al., 2005[18]	*In vitro*	Nickel-titanium (Ni-Ti) and copper-nickel-titanium (Cu-Ni-Ti) archwires	Acidulated fluoride agent, a neutral fluoride agent, or distilled water	Elastic modulus and yield strength, scanning electron microscopy	Pitted surface occurred on exposure, a decrease of unloading mechanical properties
15.	Taqa et al., 2021[19]	*In vitro*	Stainless steel and nickel-titanium wires	Fluoride gel	Tensile strength, surface analysis by scanning electron microscope (SEM), and energy-dispersive X-ray spectroscopy	Tensile properties were not affected but surface deterioration was evident
16.	Belasic et al., 2021[20]	*In vivo*	NiTi arch	Fluoride mouth-wash, chlorhexidine	Scanning electron microscopy	Fluorides and the antiseptic chlorhexidine do not increase corrosion
17.	Močnik et al., 2017[21]	*In vitro*	NiTi and stainless steel (SS)	Three different fluoride concentrations were studied, 0.014 M, 0.024 M, and 0.076 M	Electrochemical tests, Auger electron spectroscopy, plasma mass spectrometer	NiTi is affected at high fluoride concentrations, SS is affected at lower concentrations of fluoride
18.	Alavi et al., 2015[22]	*In vitro*	(NiTi) orthodontic wires	0.05 topical fluoride mouthwash with different acidities (G1, pH 4; G2, pH 6.6)	Loading/unloading with a Universal testing machine	Fluoride solution with more acidic pH of 4 affected the NiTi wire's load-deflection characteristics

(Contd...)

Table 1: *(Contd...)*

Sl. No.	*Author name/ year of publication*	*Study design*	*Samples and groups*	*Fluoride agent used*	*Surface corrosion resistance assessment*	*Results and inference*
19.	Huang, 2007[27]	*In vitro*	NiTi wires	Fluoride mouthwash, saliva	Atomic force microscopy	Surface roughness increased with fluoride exposure
20.	Gupta et al., 2018[28]	*In vitro*	NiTi orthodontic archwire	Phos-Flur gel (1.1% sodium acidulated phosphate fluoride, APF, 0.5% w/v fluoride, pH = 5.1) and Prevident 5000 (1.1% sodium fluoride neutral agent, 0.5% w/v fluoride, pH = 7).	Universal testing machine for strength, SEM for surface analysis	Fluoride mouthwashes/ gels do affect the structural surface qualities and strength of wires
21.	Abbassy, 2016[23]	*In vitro*	NiTi and stainless steel (SS)	Acidulated fluoride gel	Scanning electron microscope (SEM)	Fluoride application caused deterioration in surface properties of Ni-Ti wires when compared to stainless steel wires

one study.[17,19,23,28,30] Three different types of mouthwash were used in Schiff's study,[12,14] Elmex mouthrinse (amine fluoride) at pH 4.3, Meridols (125 ppm) at pH 4.2, Acoreas (65.9 ppm) at pH 4.5. When used as a paste or in an artificial saliva medium, the concentration of fluoride used was 1500–2250 ppm fluoride.

Discussion

Effects of Fluoride on Orthodontic Wires

Nickel-titanium and Titanium-based Alloys

Nickel-titanium wires are routinely used in the initial leveling and alignment phase as it has superelasticity and shape memory. These wires have corrosion resistance due to the surface layer of oxides (TiO_2). This oxide layer also prevents the systemic and local release of free nickel ions which is potentially toxic and causes an allergic reaction. However, literature shows that this protective layer is compromised by fluoride solutions and dental procedures using fluorides.[10–13,16] Perinetti et al. compared two types of NiTi archwire in an artificial medium with fluoride at lower pH with thermocycling and concluded that surface roughness was present in both NiTi wires with Thermaloy showing greater surface roughness than NeoSentalloy.[10]

Heravi et al. compared commercially available different NiTi archwires and stainless-steel wire with different concentrations of sodium fluoride (NaF) in artificial saliva; they found a direct relationship between fluoride content and corrosion. They concluded that stainless steel corroded more than NiTi alloys.[11] Schiff et al. analyzed the corrosion of NiTi alloys, titanium molybdenum alloy (TMA), and titanium in three fluoride mouthwashes, Elmex pH 4.3, Meridol pH 4.2, and Acoreas pH 4.5, and recommended that Elmex for NiTi-wires and TMA-based wire, Meridol/Acoreas for Ti-Nb wires.[12] Schiff et al. analyzed the corrosion between five different alloys in brackets and concluded that stannous fluoride and sodium fluoride showed high corrosion risk.[16] Yanisarpan et al. concluded that acidulated phosphate fluoride (APF) corroded stainless steel, NiTi, and TMA brackets.[14] Katić compared the galvanic corrosion between uncoated NiTi (uNiTi), nitride-coated NiTi (NiTi), and rhodium-coated NiTi (RhNiTi) archwires in the presence of topical fluoride gels and concluded that there is a decrease in corrosion resistance of uNiTi and NiTi with a high concentration of HF but the corrosion resistance of RhNiTi increases with repeated exposure of HF.[30]

Pulikkottil et al. when compared corrosion between five different alloys in NaF rinse at 0% and 0.5% concentrations and concluded that sodium fluoride caused corrosion of all the wires to varied extent. 0.5% acidic fluoride was implicated in reducing corrosion resistance in all wire materials.[13] Iijima et al. compared the corrosive property of ion-implanted NiTi wire (Neo Sentalloy Ionguard) against nonimplanted NiTi wire (Neo Sentalloy) in fluoride mouthrinses in concentrations of 450 ppm and 900 ppm and concluded that both wires underwent corrosion in fluoride mouthrinses but nonion-implanted NiTi wire had higher breakdown potential.[26] Fais et al. also concluded that exposure to toothpaste (immersion) does not affect titanium *per se* but regular brushing affects titanium topography and roughness.[24] The associated effects of toothpaste abrasives and fluorides seem to increase roughness on titanium-brushed surfaces. Ramalingam et al. concluded that topical fluoride agents such as fluoride rinse and fluoride gel alter the mechanical properties of NiTi wires.[17] Walker et al. studied the effects of AFP on NiTi and copper NiTi and concluded that exposure to APF causes pitting of the surface and decreases the mechanical properties of wire.[18] Huang and Gupta et al. also studied the effects of topical fluoride mouthwashes on NiTi wires and concluded that fluoride mouthwashes/gels do affect the structural surface qualities and strength of wires.[27,28] Alavi et al. studied 0.05 topical fluoride mouthwash with different acidities (G1, pH 4; G2, pH 6.6) and concluded that fluoride solution with a more acidic pH of 4 affected the NiTi wires load-deflection characteristics.[22] Močnik et al. studied the effects of three different fluoride concentrations of 0.014 M, 0.024 M, and 0.076 M on NiTi and stainless steel and concluded that NiTi is affected at high fluoride concentrations and SS is affected at lower concentrations.[21] Abbassy studied the effects of acidulated fluoride gel on NiTi wire and stainless-steel wire and concluded that fluoride application caused deterioration in surface properties of Ni-Ti wires when compared to stainless steel wires.[23] In contrast, Belasic et al. studied the effects of fluoride mouthwash and chlorhexidine mouthwash and concluded that fluorides and the antiseptic chlorhexidine do not increase corrosion.[20]

While most of the studies supported that fluoride in all forms tended to corrode the NiTi products, the study by Belasic et al.[20] has given a contrast finding that fluoride did not increase corrosion.

Effect on Stainless Steel Wires and TMA

The studies by Heravi et al., Schiff et al., Yanisarapan et al., and Pulikkottil et al. concluded that stainless steel archwires were corroded by fluoride ions.[3,11,13,14,16] Heravi et al. concluded that stainless steel was more susceptible to corrosion than NiTi wires. Yanisarapan et al. found that TMA wires had more surface roughness compared to stainless steel whereas Pulikkottil et al. had a contradictory finding saying that TMA had better corrosion resistance when compared to stainless steel. Yanisarapan et al. also assessed the cell viability of gingival fibroblasts reporting a decreased viability when 1.23% APF gel is used compared to fluoride toothpaste.

Effects on Orthodontic Brackets

Yanisarapan et al. compared the galvanic corrosion of 12 sets of 20 brackets in 1.23% acidulated phosphate fluoride (APF) and fluoridated toothpaste and concluded that APF gel caused more corrosion of stainless-steel brackets than the fluoride toothpaste.[13] Schiff et al. compared the corrosion property of three different brackets: cobalt-chromium, iron–chromium–nickel, and titanium with three types of mouthwashes (Meridol, Elmex, Acorea) and concluded that the Co–Cr bracket materials were resistant to corrosion with all three fluoride mouthrinses but Ti and FeCrNi brackets were susceptible to corrosion.[3] They suggested that stannous fluoride caused the destruction of the passive layer in both the brackets. Chantarawaratit et al. concluded that acidulated phosphate fluoride gel causes corrosion of orthodontic brackets with used brackets being more susceptible than new brackets. He suggested that acidulated phosphate fluoride may be avoided when using fixed metal appliances.[15]

Effects on Orthodontic-fixed Retainer

Simindinger studied the effects of fluoride-based artificial saliva medium on lingual bonded retainers and concluded that twisted wires experience significantly greater corrosion rates than solid wires of the same. Gold plating protects against corrosion. Fluoride increases the susceptibility of most wires to corrosion.[29]

Mechanism Suggested

The corrosive effect on the metallic appliances has been due to fluoride ions reacting with the hydrogen ions derived from bacterial activity and other environmental sources like food. The resulting hydrogen fluoride is highly acidic and damages the passive oxide film on the metallic components.[18] That is the reason when the pH of the fluoride medium is low like in the case of APF gel, the corrosion action is found to be more.

Summary

From the various studies it is evident that metallic archwires like stainless steel, NiTi, and TMA were susceptible to corrosion by fluoride ions used in various forms like toothpaste, 1.23% APF gel, or mouthrinses. Only one article by Belasic et al.[20] has a contrary finding that NiTi wires are not corroded by fluoride. With reference to the degree of susceptibility to corrosion, no consensus could be reached in regard to materials since contradictory findings were reported with one study saying SS corroded more than NiTi (Heravi) while another study Yanisarapan et al. quoted that TMA had more surface roughness than stainless steel and the study by Pulikkottil et al. concluded that TMA had better corrosion resistance than stainless steel. Yanisarapan et al. and Chantarawaratit et al. concluded that acidulated phosphate fluoride caused more corrosion than fluoridated toothpaste. The low pH in APF gel is said to be the contributing factor. Not only the archwires but metallic brackets and retainer wires have also been reported to corrode in the presence of fluoride ions. Both stainless steel and titanium brackets corrode with fluoride ions whereas cobalt-chromium brackets are resistant to corrosion with fluoride.

Conclusion

Since most of the studies reported suggest that fluoride ions are capable of causing corrosion of metallic orthodontic appliances, attention should be paid while prescribing fluoride agents for orthodontic patients. Most of the studies conclude that acidulated phosphate fluoride is more corrosive than fluoridated toothpaste. The degree of corrosion seems to be directly correlated to the acidity of the medium and the concentration of fluoride ions. With regard to the material of archwires, no significant difference could be found with reference to corrosion with all stainless steel, NiTi, and TMA wires having susceptibility to corrosion by fluoride ions. Co-Cr brackets are resistant to corrosion by fluoride while stainless steel and Ti brackets are susceptible.

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