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Literature Review

Release of nickel and chromium ions from stainless steel brackets as a result of long-term exposure to commonly used toothpaste

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ABSTRACT

Background: Brackets in fixed orthodontic appliances are mostly made from metal or stainless steel. Maintaining oral hygiene by brushing the teeth with toothpaste during orthodontic treatment is important. One of the ingredients in toothpaste, sodium fluoride, can cause degradation of the stainless-steel surface, which has the potential to corrode or release metal elements. **Purpose:** the purpose of this study is to describe the Nickel and chromium ion release of stainless-steel brackets against toothpaste use in orthodontic treatment by means of narrative review. **Review:** The main corrosion products of stainless-steel brackets are nickel and chromium. Toothpaste detergents contain sodium lauryl sulfate, which can cause the release of nickel ions due to the presence of sodium ions, which can trigger redox reactions. In addition, the fluoride content will combine with hydrogen to produce hydrofluoric acid, which can damage the oxide layer on orthodontic wires, resulting in the release of metal ions such as nickel and chromium. The effects of the release of these ions can be carcinogenic, cause hypersensitivity reactions, and cause cytotoxicity. Corrosion causes the dissolution of filler metal, resulting in weakened bracket material and increased friction, leading to delayed tooth movement. **Conclusion:** Toothpaste can affect the release of nickel and chromium ions in stainless steel brackets in the presence of sodium and fluoride.

Keywords: stainless steel bracket; nickel; chromium; toothpaste; medicine.

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INTRODUCTION

Fixed orthodontic appliances are orthodontic devices that are used for orthodontic treatment by attaching directly to the teeth with an adhesive material and are not removable by the patient.[1] The functions of using fixed orthodontic appliances are to correct dental, skeletal, and soft tissue abnormalities of the dentofacial region, which affects a person's aesthetic appearance and increases self-confidence for the wearer. The need for orthodontic treatment is currently increasing due to increasing public awareness, and it has become part of the lifestyle. [2]

The components of fixed orthodontics consist of brackets and tubes, rings (bands), arch wire, and accessories in the form of elastic or rubber (elastic and powers chain). The bracket is one of the essential components of a fixed orthodontic appliance that serves to deliver the forces imposed by the activated arch to the teeth. The type of bracket that is often used is the edgewise bracket, where the arch wire groove is wide in the mesiodistal direction, while the Begg bracket has a narrower groove of the arch wire that is held in place with a locking pin.

The most commonly used bracket is made of metal or stainless steel. Stainless steel contains 8–12% nickel, 17–22% chromium, and other elements such as copper, iron, manganese, silicon, and sulfur. Stainless steel brackets have advantages over other materials due to their physical and mechanical properties needed in orthodontic treatment, namely non-toxic, flexible, high strength, high resilience, relatively low price, and corrosion resistance, although the corrosion resistance of stainless steel varies greatly.[2–4] The existence of these advantages causes stainless steel to be widely used as brackets, wires, and bands in orthodontic treatment.

Stainless steel brackets are bonded in the oral cavity for approximately 2–3 years. While in the oral cavity, the bracket can be exposed to the oral environment and other substances from outside, such as food, drinks, the use of mouthwash, and toothpaste.[5] Orthodontic treatments for a long period of time can potentially increase the risk of caries due to the difficulty of cleaning plaque and food debris. A way to reduce the risk of caries is to brush your teeth with toothpaste. Toothpaste is a semi-solid preparation that is effective as a medium and consists of a mixture of

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abrasive materials, cleaning agents, and additives so that the active substance can work on the tooth surface. The main objective is to make the tooth surface more resistant to damage by oral bacteria without damaging the teeth or oral mucous membrane. Dental cleaning preparations can be in the form of pastes, gels, pastes with colored coatings, powders, or liquids.[6] Each toothpaste on the market certainly has a different content. However, one of the main ingredients contained in toothpaste is sodium fluoride. Fluoride ions can cause the degradation of stainless-steel surfaces, which can aggravate corrosion.[3]

Corrosion occurs with the release of positive metal ions from orthodontic alloys to form more stable compounds such as chlorides, sulfides, and oxides.[7] Corrosion and ion release of orthodontic devices in the oral cavity can have several effects, including: (i) when corrosion and ion release occur, corrosion products will be absorbed by the body and can cause local and systemic effects. (ii) The corrosion of metals can have an effect on the physical properties of stainless steel and the mechanical ability of orthodontic devices.[6–11] Based on the problems mentioned above, this narrative literature review aims to discuss the effect of toothpaste use on the release of nickel and chromium ions in stainless steel brackets in orthodontic treatment.

REVIEW

Stainless Steel Bracket

Brackets are a very important component in orthodontic treatment. The development of materials for brackets is a concern for clinicians seeking to achieve optimal orthodontic treatment.[5] Materials used for brackets include ceramic, plastic, and metal. Plastic brackets are generally made of polycarbonate or polyurethane. Plastic brackets have advantages in terms of aesthetics but have many disadvantages. The disadvantages include easy discoloration and odor due to water absorption, so they need to be replaced with new ones. These brackets also have low abrasion resistance and deformation resistance, which can cause erosion of the bracket surface when brushing the teeth, which can weaken the bracket.[9]

In addition to plastic brackets, another type of aesthetic bracket that is currently in demand is ceramic brackets. However, the characteristic of ceramics, which is that they are naturally brittle, results in an increased occurrence of fractures in the bracket during debonding. The part of the ceramic bracket that tends to fracture the most is the wing of the bracket. In addition to the naturally brittle characteristic of ceramic brackets, it is necessary to consider other factors that affect the durability of the bracket itself. Some intraoral factors that affect the durability of ceramic brackets are corrosion, mastication, plaque, saliva, bone density, number of teeth, root surface area, anatomical structure, and occlusion.[10,11] Compared to plastic and ceramic brackets, metal brackets do not have good aesthetic value. However, metal brackets have good physical and mechanical properties compared to ceramic brackets, so metal brackets are commonly used in orthodontics.[9]

Metal brackets have near-ideal properties and are most commonly used in fixed orthodontic treatment. Most of the metal brackets used today are made of stainless steel.[6,8] Stainless steel orthodontic brackets generally consist of ferrous metals and non-ferrous metals. The ferrous metal content in stainless steel is iron (Fe) and carbon (C). Iron is an important metal in engineering, but pure iron is too soft and brittle as a material for work, construction, or aircraft. Therefore, iron is always mixed with other elements, especially carbon. Ferrous metals are also called carbon or carbon steel because they have the highest carbon content, which affects their hardness.[12]

Another substance found in stainless steel orthodontic brackets is non-ferrous metals, which contain nickel (Ni) and chromium (Cr). Nickel is a hard metal with a specific gravity of 8.7 and a melting point of 1455 °C, making it easy to form in cold or hot conditions. The corrosion-resistant nature of nickel is widely used in the chemical industry, electrical appliances, and medical devices. Another non-ferrous metal contained in stainless steel brackets is chromium, which is a bluish-white metal that is harder than glass but brittle. Chromium metal has a melting point of 1550 °C, a boiling point of 2477 °C, and a density of 7.138 gr/cm^3. Chromium is easily soluble in acids such as hydrochloric acid, sulfuric acid, and nitric acid. In addition, chromium can be used to improve tensile strength and corrosion resistance.[12]

Stainless steel alloys in orthodontic appliances rely on the formation of a passive surface oxide film to resist corrosion. However, this protective layer is imperfect. It can be destroyed or removed by mechanical and chemical disturbances. Even in the absence of disturbance, the passive oxide film can slowly dissolve due to acidic conditions or the presence of chloride ions.[13] The corrosion and ion release of orthodontic appliances in the oral environment are caused by two main factors. First, it's caused by the manufacturing process, which includes the type of alloy and characteristics of the metal used. Second, it's caused by environmental factors such as mechanical stress, diet, salivary pH, patient health, and patient psychosomatic conditions.[6,13,14]

Toothpastes

According to the American Council on Dental Therapeutics, toothpaste is a material used with a toothbrush to clean places that cannot be reached with the aim of cleaning teeth from the debris of food or drinks to maintain the surface of the teeth, maintain the health of teeth and gums, and eliminate odors caused by bacterial activity in the mouth.[15] The composition of toothpaste includes abrasives, water, moisturizers, adhesives and binding agents, flavor enhancers, bleaches and detergents, preservatives, and therapeutic ingredients. Abrasives are the main ingredient in toothpaste, making up 30%–40% of the content. Abrasives function to clean and polish the tooth surface without damaging the enamel, maintain pellicle thickness, and prevent stain accumulation. Ingredients that are often

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used include sodium bicarbonate, calcium carbonate, and potassium sulfate. Bicarbonate is added to reduce the acidity of dental plaque, which acts as an inhibitor of plaque mineralization and changes the pH to reduce calculus formation. Water serves as a solvent for some ingredients and maintains the consistency of the toothpaste.[15]

Other ingredients found in toothpaste are moisturizers that prevent water evaporation and retain the moisture of the paste. Ingredients that are often used include glycerin, sorbitol, and water. These moisturizers make up 10%–30% of the paste content. The adhesive or binder acts as a binder for all ingredients and helps to give texture to the toothpaste. Materials that are often used include carboxymethyl cellulose, hydroxymethyl cellulose, and carrageenan. Toothpastes on the market generally contain flavor enhancers that can cover the taste of other ingredients that are unpleasant, especially sodium lauryl sulfate (SLS), and fulfill consumer tastes. Other ingredients that are often used include peppermint, menthol, eucalyptus, and saccharin.[16]

Toothpaste contains whitening or detergent materials that function as surface tension reducers and loosen the bond of debris with teeth so that it can help the cleaning process. Ingredients that are frequently used include SLS and sodium N-lauryl sarcosinate. Preservatives are used to prevent bacterial contamination and maintain product authenticity. Commonly used ingredients are formalin, alcohol, and sodium benzoate. Other ingredients contained in toothpaste are therapeutic ingredients contained in several active ingredients that have therapeutic functions for oral health, including: (i) Fluoride functions as an anti-caries and as a remineralizer of early caries. The ingredients used include sodium monoflourophosphate and sodium fluoride. (ii) Desensitizing agents serve to reduce or eliminate dentin sensitivity by means of a direct desensitizing effect on nerve fibers. Common materials used include strontium chloride, strontium acetate, potassium nitrate, and potassium citrate.[16]

Every toothpaste that is spread on the market certainly has different ingredients, including the ingredients contained in orthodontic toothpaste. The difference between the ingredients of orthodontic and non-orthodontic toothpaste is the presence of colostrum in orthodontic toothpaste, but the other ingredients are the same as in non-orthodontic toothpaste. A study showed that the release of nickel and chromium ions was smaller in the orthodontic toothpaste solution than in the non-orthodontic toothpaste solution. The smaller release of nickel and chromium ions in orthodontic toothpaste solution is caused by the presence of colostrum, which functions to moisten the oral cavity environment so that the pH of orthodontic toothpaste solution is higher than the pH of non-orthodontic toothpaste solution.[16]

DISCUSSION

Corrosion is an electrochemical reaction between metal materials and the surrounding environment. There are two types of corrosion reactions, dry corrosion and wet corrosion. Dry corrosion occurs without the involvement of water or electrolyte fluids, when metals react to form compounds such as oxides and sulfides, for example oxidation of metal surfaces during soldering or heating procedures. Wet corrosion occurs in the presence of water or electrolyte fluids. The corrosion process that occurs in the oral cavity is wet corrosion due to the presence of liquid electrolytes, namely saliva.10 In the oral cavity, corrosion occurs by the release of positive metal ions from orthodontic alloys into more stable compounds such as chlorides, sulfides, and oxides. Corrosion is a chemical property of the alloy that can affect other properties, such as aesthetics and strength, due to the release of elements that affect the composition of the alloy. The main corrosion products of stainless-steel brackets are iron (Fe), chromium (Cr), and nickel (Ni). The release of nickel and chromium ions is caused by the process of interaction between a solid material and the chemical and physical environment, causing a loss of structural integrity. The corrosion process can also reduce the quality of the bracket due to the release of metal ions from stainless steel.[17]

Toothpaste is made from a variety of ingredients with different functions and some additional ingredients, including sodium fluoride, sodium saccharin, sodium hydroxide, sodium benzoate, sodium phosphate, sodium lauryl sulfate (SLS), sodium silicate, sodium chloride, and other contents are aqua, hydrated silica, sorbitol sol, glycerin, ethoxilatedstearyl fatty acid, carrageena, aroma, titanium dioxide, amyloglucosidase, citric acid, glucose oxidase, potassium thiocyanate, lysozyme, lactoferrin, lactoperoxidase, flavor, mica, and zinc sulfate.[18] One of the constituent ingredients is surfactant, which is an ingredient that can form foam from toothpaste. Surfactants are usually added in the form of synthetic detergents because they provide an effective foaming effect and are widely used in toothpaste in the form of anionic surfactant detergents (fatty acid soaps).[19]

Toothpaste detergents contain sodium lauryl sulfate, which can cause the release of nickel ions due to the presence of sodium and sodium ions, which can trigger electrochemical reactions. Sodium ions will react with water to form hydroxide bonds that occur at the cathode. In addition, sodium lauryl sulfate also contains sulfate (SO_4), which can affect the release of metal ions. Sulfate ions will react with water to form sulfuric acid, which occurs at the cathode (reduction reaction). The presence of these ions results in the release of the protective layer (Cr_2O_3), which is the outermost layer of the stainless-steel bracket.[20,21]

Another possible cause of nickel and chromium ion release is the presence of fluoride ions found in detergent and non-detergent toothpastes, mouthwashes, and prophylactic gels that aim to prevent caries because fluoride ions can cause degradation of stainless-steel surfaces. The released fluoride ions will combine with hydrogen to produce hydrofluoric acid (HF), which can damage the oxide layer on orthodontic wires, resulting in the release of metal ions such as nickel and chromium. Fluoride can reduce the

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resistance of stainless-steel orthodontic wires to corrosion. This may be due to the effect of fluoride on the wire's protective coating.[22–24]

Citric acid ($C_6H_8O_7$) content in toothpaste has high H^+ particles, and it may increase if it reacts with metals, which can cause faster corrosion rates.[17] It is because citric acid is a strong metal complexing agent that is able to form different metal complexes with metals in solution or with metals of the surface oxide. Citric acid has been shown to induce ligand- or complexation-induced metal release in stainless steels. Depending on the pH, strength of the formed complex, and adjacent bonds, the complex may detach from the surface.[25]

Corrosion by products in the oral cavity is usually absorbed into the body and can cause systemic and local effects. Nickel and chromium are known to stimulate type IV hypersensitivity reactions in the body, mediated by T lymphocytes.[17] Free nickel ions are known to most commonly cause allergies in the form of contact dermatitis in women.[26] The release of nickel ions from archwires can also result in gingival hyperplasia, labial desquamation, angular cheilitis, swelling, and burning in the oral mucosa.[26] Nickel and chromium ions released into saliva due to the corrosion process have potential carcinogenic, mutagenic, and cytotoxic effects.[17]

Corrosion of orthodontic appliances can cause adverse effects due to the absorption of free metal ions in saliva, such as changes in cellular function, decreased DNA synthesis, and enzyme inhibition, as well as mechanical properties that affect the effectiveness of orthodontic appliances.[17] The biologic effect of the corrosion product was measured by gingival fibroblast cell viability in a released metal ion solution. The physical effect of the released metal ions was evaluated by the morphology of the appliance surface and the surface roughness of the brackets and archwires.[27]

The level of metal corrosion is influenced by the composition of the material as well as chemical reactions in the surrounding environment. Nickel ions are soluble in liquids, so the length of time an archwire is exposed to toothpaste affects the release of metal ions. Nickel ions have a higher tendency to be released than chromium ions because nickel atoms are not strongly bound to intermetallic compounds.[28] In addition to metals, nickel ions are present in nature and are easily exposed through drinking water, vegetables, cereals, grains, and the atmosphere. The average nickel ion present in food is 300–500 µg/day and in water, 20 µg/L. Nickel at a minimum concentration of 1.18 µg damages human gingival fibroblasts. Even nontoxic concentrations can result in adverse biological effects on oral mucosal cells when combined with prolonged orthodontic treatment. Nickel is an ion that is harmful to both animals and humans and is carcinogenic to the respiratory system and nasal cavities. Some studies also suggest that long-term exposure to dental materials containing nickel can affect monocytes and oral mucosal cells. Nickel ions act as a strong immune reaction medium and can cause severe hypersensitivity reactions, contact dermatitis, asthma, and cytotoxicity. The age range that most often experiences allergic reactions to nickel ions is 10–20 years, and in that age, range is the age where most orthodontic treatments are performed. The diagnosis of nickel ion allergy is based on patient history, clinical circumstances, genetic factors, and patch test results. Another component that can cause allergy and toxicity is hexavalent chromium. But this element is rarely found in both in vivo and in vitro studies.[12,17,21]

Along with the release of elements from metals or alloys, corrosion of orthodontic wires can cause the metal filler to dissolve and lead to roughening of the surface and weakening of the appliances. Weakening of the bracket material due to corrosion and ion release can result in the detachment of the bracket wing from its base and can severely affect the ultimate strength of the material, leading to mechanical failure or even fracture of the orthodontic materials.[29] Another problem that can occur is friction. Friction occurs due to the friction of two material surfaces, causing erosion of the contacting surfaces. Friction is influenced by different bracket and wire combinations (material size, shape, and angulation), the ligation effect, and the interaction of the orthodontic appliance with the oral environment. Frictional resistance has always played a vital role in orthodontics and works best when friction is minimized. Friction is usually an unfavorable force; it opposes the sliding mechanics of tooth movement, can disturb light continuous forces, and can destroy guided tooth movement along the arch wire.[28] Corrosion that occurs on metal surfaces can increase the friction between two different metal surfaces. This causes delays in tooth movement and discomfort for the patient, so optimal treatment cannot be achieved.[27]

CONCLUSION

Toothpaste can affect the release of nickel and chromium ions from stainless steel brackets in the presence of sodium and fluoride. The release of nickel and chromium ions can cause corrosion of stainless-steel brackets, which occurs through electrochemical processes between metal materials and the oral environment and toothpaste materials to form compounds such as oxides and sulfides.

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