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CONTEMPORARY DYNAMICS OF BIODEGRADATION IN ORTHODONTICS

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Abstract

Orthodontic therapy includes active and passive components which are formed by different types of metals, elastics, and polymers to manage various malocclusions. As these Orthodontic components come in contact with oral tissues they induce cytotoxic, allergic, inflammatory, or genotoxic reactions. Though the combination of metal alloys and other components used during treatment are biocompatible still it has been shown that metallic alloys release ions which are of significant clinical concern as the metals react with electrolytes in the oral cavity which includes saliva and other acidic or basic food items hence producing electrochemical reaction with oral tissues and causes biodegradation and corrosion.

This article highlights the different Orthodontic components and their degradation process along with biological reactions which are responsible for alteration in the biocompatibility of metal alloys and further explores the forthcoming strategies to overcome the degradation process.

KEY WORDS: Biodegradation, Orthodontic appliances, Biocompatibility, Dental materials, Corrosion.

INTRODUCTION

Orthodontics is a specialty of dentistry that uses a plethora of devices made from myriad materials. It is imperative that these appliances are made up of materials that must be harmless as far as possible. These materials require special consideration as they are present in the oral cavity for a long period of time till the completion of the orthodontic therapy.

The degradation of substances that is caused by the vital activity of an organism is not the same when we consider the degradation of metals in the oral cavity. However, the biodegradation which occurs in the oral cavity is associated with some organic materials if the parts of the molecules are similar to those of natural molecules so that they can be degradable by enzymes. As the oral environment is great for the biodegradation of metals because of its warm, ionic, enzymatic, and microbiological properties, the corrosion of alloys can be considered to be degradable. [1,2]

The orthodontic appliance must have excellent resistance to surface degradation while communicating with the oral environment as it is important for biodegradation and durability of the alloys. [3] of the effect of food and beverages on enamel and restorative ma-trials by SEM and Fourier transform infrared spectroscopy.

Microsc Res Tech 77:79–90 Sari ME, Erturk AG, Koyuturk AE, Bekdemir Y (2014) Evaluation of the effect of food and beverages on enamel and restorative ma-trials by SEM and Fourier transform infrared spectroscopy.

BIOMATERIAL AND ITS IMMUNOLOGICAL REACTIONS

When a material enters, or is placed within the body, it arouses the host defense mechanisms that have been evolved to cause its rejection, these mechanisms are confined to the inflammatory response. Many of the biomaterials are potentially capable of arousing an immune response either in their own right or by acting as haptens and combining with tissue components. [4] The latter almost certainly is the case with a variety of metals, including chromium, nickel, and cobalt, and may also occur with plastic materials, particularly if they contain monomers.

Patients receiving Orthodontic appliances may develop cell-mediated immune responses to the various metals contained in them. In orthodontics, allergic reactions to nickel and chromium release from the appliances have been reported and well-researched with the conclusion that has been equivocal.

The immunological basis of sensitivity to metal is clear. It has been shown that in tissue culture, lymphocytes from the blood of sensitive individuals will respond to stimulation with appropriate metal salts by undergoing blast transformation. [5] Therefore a cell-mediated immune response occurs in the sensitized individual. As yet, the humoral immune response has not been impacted in metal sensitivity.

EVALUATION OF BIOCOMPATIBILITY

Phases in testing for biomaterials

• Primary phase test is performed initially and is often in vitro in nature, but the primary test can also include some animal studies to measure systemic toxicity

• Secondary phase test is always conducted in animals- These tests explore beyond mutagenicity or toxicity towards issues such as inflammation, allergy, and other sub-lethal and chronic biological responses

• Usage phase of testing is performed in animals or humans and it requires material to be placed in an environment clinically relevant to use. [6](Figure 1)

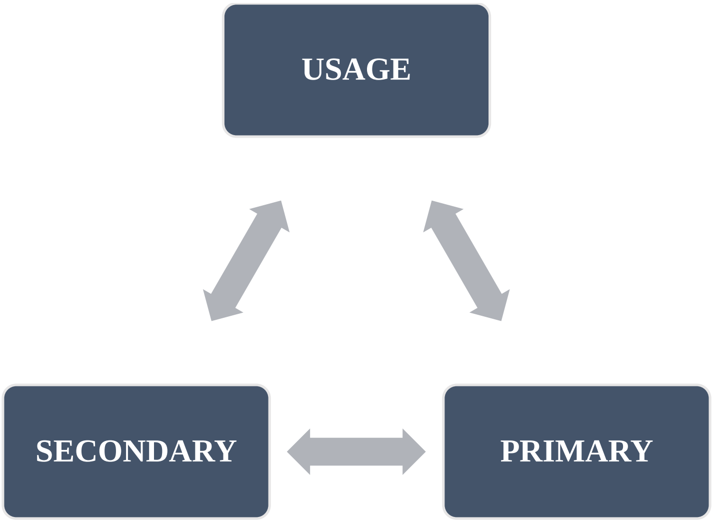

Figure-1: Different schemes for testing of biomaterials

The first key point to know about biodegradation and biocompatibility is that there is no truly inert biomaterial. The interactions with complex biological systems occur, whenever a material comes in contact with living tissue, this interaction depends upon the host, the material, and what type of force and condition are implied on the materials.

• The Second key point of biocompatibility and biodegradation is that it is an ongoing and vigorous process. The response by a body to the material can change with time, because of the changes in the body due to aging or disease and the corrosion process, or changes in stress may change the properties of materials

• The third key point is that it is not only about the property of a material but the interaction of a material with its surroundings.

Key principle determining the adverse effect of materials(Figure 2)

- The first factor involves various types of metal corrosion and metal degradation; the biocompatibility of material depends to a large degree on the degradation process.
- The second key factor that affects biocompatibility is the surface characteristics, surface properties may affect the corrosion properties of a material or may promote adherence of bacteria.

Corrosion not only depends upon the material composition but also on the biological environment in contact with the material. The biological requirement of a material depends on how it is exposed to the body.

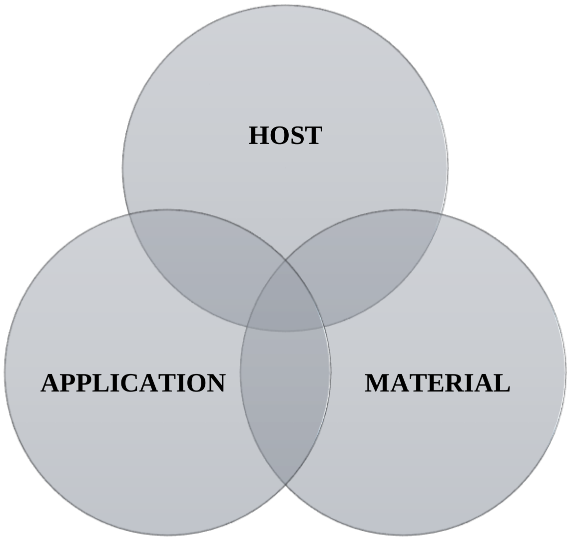

Figure 2: Determination of orthodontic biomaterial

MATERIALS IN ORTHODONTICS

1. Elastics

In orthodontics, elastomeric products are used as continuous modules and ligatures for engaging wires and retracting teeth. Orthodontists prefer using elastomeric ligatures rather than stainless steel ligatures. With the spread of rubber bands, there are concerns about the deterioration of elastomer chains. Continued efforts have been made to minimize plaque retention of the elastomer, elastomers have been introduced to reduce the risk of decalcification at the edges of the enamel, taking into account the biodegradable aspects of rubber bands. The elastomer and its chains are polyurethanes, thermosetting polymers with-(NH) (C = O) O {urethane bond}, formed by step reaction or condensation polymerization. Elastic polymers such as rubber have a long-chain, slightly cross-linked structure. Different material companies manufacture polyurethane products in different forms. There are two main methods of processing modules:

- Injection moulding
- Stamping

The disadvantage of elastomer products is that they are not inert in the oral environment. Water acts as a plasticizer that weakens the intramolecular force of polyurethane and causes deterioration. Increased leaching of the elastomer module when immersed in water is shown by chromatographic analysis. The degradation of elastomeric products depends on:

- Different states whether dry or wet including water, acidic beverages, and food particles
- An acidic or neutral pH environment

The oral environment and its effect on the particular structure are caused because of stress absorption on the macromolecular chain orientation and its elongation. It appears as micro-tears on the surface that propagate from the edges to the center causing fracture lines. The environmental effects of elastics and elastomers are associated with deformation and force degradation. These show more force decay when immersed in basic solution, whereas no deleterious effect is seen on the properties of elastics with glutaraldehyde solution while the sterilization process. [7] The deleterious effect of water immersion and loading along with environmental effects may attribute to the hydrolysis of polyurethanes and their compounds, this results in elastomeric chain weakening and contributes to the degradation of force. [8]

2. Resin-based composite/polymers

When fixing the bracket to the tooth, cement fixation with adhesive is important for orthodontics. Unfilled polymers are traditionally used as adhesion promoters for composites. The only difference between synthetic resin composites and fluid-bonded polymers is the absence of fillers. These systems differ in composition from their corresponding systems in that they have a higher proportion of comonomer (eg TEGDMA) compared to monomers.

Polymerization shrinkage depends on the volume of the resin. Unfilled plastics are expected to shrink more. In addition, high proportions of comonomer present in the materials cause excessive shrinkage and also these unfilled plastics have a very large surface area-to-volume ratio, which increases the water absorption rate and the thickness of the oxygen inhibitory layer.

Polymers degradation can be characterized into two areas:

- Random; includes rupture of chain induced by exposure to oxygen, ozone, foreign agents, and ultraviolet radiation. This degradation of random sites is seen in the structured polymer, which results in the release of large fragments
- Chain depolymerization; consists release of monomer in a more proportionate manner(de-propagation)

De-propagation is the reverse of polymerization, where breakage of the bond is initiated at a defect site in the chain and a hydrogen atom is escaped from the structure of the polymer. This degradation includes the reaction of free radicals and released hydrogen atoms. It is seen that water sorption in composite resins leads to microcracks or diffusion of channels due to swelling. Localized enzymes and bacteria may penetrate the resin surface and initiates the degradation process.

Due to the interaction between solubility, water absorption and polymerization, higher concentrations of monomer and unsaturated carbon bonds tend to degrade the material. Enzyme metabolites are present on the resin surface, and Munksgaard and Freud show enzyme-induced degradation of methacrylate polymers and process hydrolyzability. Composite resins are often covered with a protein film (pellicle) present on the surface layer, which can reduce reactivity with substances that can have a dangerous effect on the environment or the enzymatic activity of resin molecules. [9] Matasa, studied the activity of aerobic and anaerobic microorganisms that can weaken composite resins and reduce adhesive strength. Evidence of microbial attack on the adhesive attached to the stripped bracket has been presented, with effects due to the ability of the microorganisms to metabolize the adhesive. [10]

Leaching of Orthodontic Adhesives

Immersion in water releases 50% of the chemicals that can leach the resin in the first few hours while soaking in ethanol releases 75% of the molecules that elute in the same amount of time. No further elution of the resin was observed after 24 hours of immersion with any solvent. The solvent showed differences affecting the composition and amount of elution material when used in leaching experiments. The ethanol bath accelerates the decomposition process of the resin composite compared to immersion in water and also promotes the elution of leachable species in various proportions. The amount and composition of the eluted material are important factors in the toxicity of resin adhesives. Eluents include methacrylic acid induced by enzymatic hydrolysis, fillers, benzoic acid which results from the degradation process of the initiator- benzoyl peroxide, and other featureless substances derived from accelerators and catalysts during polymerization. [11]

Potential Estrogenicity of Dental Resins:

Estrogenicity is the chemical ability of a hormone to act as estrogen, if these chemicals are not native to the body, it is called Xenoestrogen. The competitive binding of estrogen-like molecules, such as bisphenol A (BPA) to natural hormone and its receptors. The presence of these chemicals can alter the reproductive and developmental process in all animals, the concern about estrogens centers around Bisphenol-A.[12]

Local Toxicity and Tissue Compatibility:

- Cytotoxicity: Before polymerization, resin-based composites are cytotoxic and immediately after polymerization no reactions are caused by the set composites
- Thermal effects of light curing units: Temperature rise associated with the curing of resin-based composite will cause irreversible pulpal damage. Hazards for eyes- like damage to the retina at high intensities of light.

Biological Effects of Resins:

- The risk of allergic response is associated with these materials and this is highest for dental auxiliaries because of frequent exposure to unpolymerized materials.
- The allergic reactions are primarily contact dermatitis, with resins acting as haptens via a delayed (type IV) hypersensitivity mechanism.
- In most severe cases anaphylactic reactions have been reported.
- Localized swelling is noticed on the upper lip associated with the application of a resin-based composite having TEGDMA. [13]

Allergic Reactions in Dental Personnel:

Dental personnel should be considered a risk group, as monomers may penetrate through latex or nitrile gloves causing allergic contact dermatitis associated with the contact with resin-based composite. Neoprene gloves are recommended as the best protection.

Inhalation of Resin-Based Composites:

- During the trimming and finishing of composite resin, mini and micro-sized particles may be produced. Inhalation of these particles may be associated with chronic lung inflammation. [14]
- Using a rubber dam, suction, water spray, and retractors can minimize the effect. Also, properly isolate the soft tissues at all times to prevent soft tissue chemical burns. [15]

Additives used in dental resins when immersed in water or synthetic saliva components can leach which includes monomers, and additives such as plasticizers, initiators, and coupling agents. Aromatic amines used as curing agents have been shown to be carcinogenic as well as toxic. Cross-linking agents like benzothiazole, dithiocarbonates, and thiuram disulfide are also toxic and known as allergens. [16]

3. Orthodontic cement

Orthodontic brackets are placed on the labial or lingual surfaces of the teeth by types of cement, and they act as means of force delivery applied on the archwire and tooth auxiliaries. The cement ideal for orthodontic bracket bonding and banding use should have the sufficient holding power to counteract displacement of normal function in the oral cavity and exert orthodontic force on the teeth. Commonly used adhesive cement for fixing brackets to teeth were glass ionomer cement (GIC) and resin-modified glass ionomer cement (RMGIC).

Despite the improved properties, the toxic effects of RMGIC are of greater concern compared to GIC and are composed of monomers and initiators such as HEMA. In addition, composite resins are incompletely polymerized, resulting in inadequate monomer and polymer conversion. Cytotoxic effects are associated with these residual monomers in the oral environment. There is a link between the RMGIC cytotoxicity and its degree of conversion, which decreases over time after the initial polymerization. [6]

Release of ions from GIC and its hybrids:

Leaching of fluoride, calcium, HEMA, camphor quinone, ethylene glycol, and DPC1. These are considered to be cytotoxic which is of specific concern in regard to possible hypersensitive reaction.

- GICs are generally cytotoxic immediately after mixing but are present in an inactive form when set.
- Resin-based GICs contain potentially allergic substances like HEMA, and should not come in contact with the skin [5,6]

4. Alloys and implants

Orthodontics include various appliances from precious and noble metals along with their alloys. Silver, Gold, Iridium, and Platinum alloys were pleasing aesthetically and they were corrosion resistant, but they lacked tensile strength and flexibility. The material that was to truly displace noble metals was stainless steel. The manufacturing methods used today to make devices; milling, lost wax casting, powder metallurgy, etc. were used earlier, and now with advancements in the manufacturing industry modern refinement of the powder metallurgy process is injection moulding.

Dozens of metals are currently used to provide strength others resist corrosion and still others enhance aesthetics. The main groups of alloys used in orthodontics are iron alloys which consist of different types of stainless steels, cobalt-chromium alloys, nickel-titanium, and titanium alloys. Alloys are available on the market for applications involving contact whether direct or indirect with connective tissue, epithelium, or bone. The long-term close contact with critical tissues, it is of utmost importance that the biocompatibility of alloys be studied and understood, especially in the field of orthodontics where the entire system is metallic.

The oral environment is ideal for the biodegradation of metals due to its thermal, ionic, enzymatic, and microbiological properties, the patient's exposure to the corrosion products of the alloy is uncertain, the abundance of nickel alloys in a wide variety of orthodontic appliances is present and these play an important role in almost all routine orthodontic procedures.

Ni-Ti alloys have 47-50% Ni and are the greatest source of Ni intraorally in most orthodontic patients. The shreds of evidence have attributed mutagenic, carcinogenic, allergenic, and cytotoxic actions to Ni in different forms and compounds. In addition to Ni, other metals such as chromium, cobalt, and iron that can leach orthodontic appliances could also pose potential health implications. [17]

Nickel alloy is used in orthodontics, where the alloy is not embedded in the tissue and it is placed in an open environment. Therefore, tests consisting of Ni alloy infusions are often used in the medical field, which is not related to orthodontic materials for clinical use. The transplantation process can be more invasive than the intraoral introduction of Ni alloys. The formation of connective tissue surrounding the foreign body reduces the reactivity of the transplanted material in the oral cavity researchers have demonstrated the biological effects of nickel and its release, focusing on the corrosive products of Ni alloys used in orthodontics. [18,19]

However, the study uses in vitro techniques that are methodologically unreliable and clinically unrelated due to the nature of the in vitro medium and oral cavity. Thus, the findings are undecided as to which products will be released. [20,21]

Metallurgy and degradation of orthodontic materials:

Corrosion and tarnish are commonly used for metals and their alloys, but they can also be applied to non-metallic materials such as ceramics, plastics, and rubber. The composition of the metal, its physical condition, its surface properties, and the chemical composition of the surrounding medium determine the type of corrosion reaction. Other important variables that affect the corrosion process are temperature, temperature fluctuations, movement or circulation of the medium in contact with the metal surface, and the type and solubility of corrosion products. [5,6]

There are various types of corrosion but corrosion associated with orthodontic appliances is widespread electrochemical corrosion because of the moist oral environment. These include various types of corrosion

1. Pitting corrosion detected on brackets and wires
2. Crevice/Gap corrosion is exposure to a corrosive environment and occurs in tight spaces. (It may also be attributed to plaque formation and various by-products of oral microbial flora.)
3. Fretting corrosion occurs as the metal wire slides over the slots in the bracket

On the other hand, tarnish is seen as discoloration of the surface of a metal or as a slight loss or alteration of the surface finish or lustre. In the oral cavity, tarnish often occurs as the formation of soft and hard deposits on the surface of metal alloys, the major cause of tarnish and its deposits in the oral cavity includes discoloration of the surface may rise on metal from the formation of thin films, including oxides, sulfides, and chlorides.

Thus corrosion and tarnish imply an attack on a material caused by a chemical or electrochemical reaction with the oral environment. Whether corrosion of a metallic material occurs or not will depend on the thermodynamic stability of the metal concerned, apart from influences on the efficiency and the aesthetic appearance of orthodontic appliances, the potential biological effects of oral corrosion have received a great deal of attention. Thus, electrochemical activity in the oral cavity has been said to cause a tissue response, either due to the current per se or to the effects of released ions in the oral environment. [10]

Biological Effects of metal alloys

In general, nickel and cobalt disrupt the phagocytosis of human polymorphonuclear leukocytes. Nickel ions may have affected leukocyte chemotaxis, which is concluded by the change in shape. These ions cause neutrophils to become non-spherical and move slowly. It also inhibits the contractile activity of calcium ions by depolarizing neutrophils in the cell membrane. Ni is also associated with chemotaxis inhibition at a concentration of 2.5-50 ppm. The nickel concentration released from the dental alloy activates monocytes and endothelial cells and suppresses or promotes intercellular adhesion molecules via endothelial cells. [22] It depends on the Ni concentration; most literature suggests that the presence of Ni carries the risk of promoting an inflammatory response in soft tissues.

Major corrosion products of stainless steel are iron, nickel, and chromium

- Nickel and chromium are noticed because they are associated with allergic, toxic, or carcinogenic effects.
- Nickel ions affect leukocyte chemotaxis and are favorable. It may inhibit the calcium-mediated contractile activity of neutrophils.
- Nickel induces T lymphocytes for the production of several cytokines such as interferon, interleukin IL2, IL5, and IL10, which stimulate cell proliferation.[23,24,25,26]

Allergic reactions from metal release

The main systemic effects of human exposure to nickel or chromium compounds are allergies, dermatitis, and asthma. Most causes of nickel and chromium allergies result from dermatological exposure to metals or compounds containing these metals. Blue jeans stud earrings and metal buttons have been found to be responsible for a significant number of cases of nickel hypersensitivity in women. [27] The ability of metals to induce dermatitis appears to be related to their corrosion patterns and modes. The products resulting from this corrosion can cause an inflammatory reaction in soft tissues, which can lead to sensitization dermatitis. There are various factors that can affect the development of metal hypersensitivity. Most important are mechanical irritation, skin infiltration, individual sensitivity, body temperature, climate, and intensity and duration of exposure.[(28,29,30)]

Kawahara, Shiota, and Yamakawa" (1968) carried out observation of the effect of various dental materials, such as metals, alloys, synthetic resins, plastics, dental cement, root canal fillings materials, and pulp-capping materials on cells in tissue culture. They found that chromium has little cytotoxicity and nickel, is moderately cytotoxic. [(32)] Rafeeq et al (2014) Corrosion in the oral cavity can release metal ions from metal orthodontic appliances. Prophylactic mouthwash can affect the release of ions from orthodontic wires. Higher Ni ion release was noticed in both types of mouthwash from the NiTi wire group than in the SS wire group and higher in the fluorinated group than in the non-fluorinated group. While Cr ion was higher for the fluoridated group than for the non-fluoridated group. [(33)] Mikulewicz et al (2014), Fixed stainless steel orthodontic appliances containing nickel, chrome, and copper were evaluated. Emission spectroscopy was used to determine metal ion concentration by inductively coupled plasma. They found that the released ions during treatment were well below the toxic dose to humans, which indicates that orthodontic treatment may not be an important source of these metal ions exposures. [(34,35,36)]

GENOTOXICITY AND CYTOTOXICITY EFFECTS

Due to corrosion, metal alloys can cause direct or indirect effects on the oral tissues and can alter the cell structures at the DNA level by inducing free radicals with effects of mutagenicity or carcinogenicity. Fixed orthodontic therapy contains various types of active and passive components out of which brackets are attached to the tooth surface from the start till the end of orthodontic treatment whereas, other components are replaced at different time intervals. [(37,38)]

- ➢ The inherent heterogeneity of each metal alloy and its use with other alloys
- ➢ The micro surface discontinuity
- ➢ The forces acting on the appliances
- ➢ The friction between wires and brackets also adds to the corrosion process.

Paulina Wolowiec et al 2017, Orthodontics has an indirect effect on cellular DNA by inducing free radicals with effects of mutagenicity or carcinogenicity through the invasion, absorption, and accumulation of free radicals into the oral cavity and biological tissues including oral, gingival, cutaneous, intestinal, and respiratory system epithelium [(39)] Anna Woźniak et al 2017, observed the toxicity of materials, apoptosis and DNA duplication of the resulting nanomaterials using polydopamine-coated nanostructures in cancer and normal cell lines. This study concludes with the genotoxicity and biocompatibility of materials and provides new data on PDA-coated materials and their toxicity. These are very important for biomedical applications. [(40)] Malik Sameer Ahmad et al 2019, showed no effect of cytotoxicity of TiO2-coated wire. Structural assessments of cell morphology and nuclear envelope structure showed no toxic effect changes of TiO2-coated SS wire on cells. There are no significant cell alterations indicating the cytotoxicity of stainless steel wires with titanium coating used in orthodontics. [(41)] Juan Pablo Loyola-

Rodriguez et al 2020 tested the genotoxicity by comet assay on human gingival fibroblasts (HGFA). All research groups have shown genotoxic effects. Significant differences were noticed between the groups, the eluate obtained from NiTi showed a 16-fold stronger genotoxic effect, and there was a difference in genotoxicity when NiTi was compared with SS and CoCr brackets. Ceramic was more genotoxic than metal brackets (SS and CoCr), but less than NiTi.[(42)]

PROTECTIVE MEASURES- PREVENTION OF CORROSION

Although it almost always happens to some degree, corrosion can be kept to a reasonable level by the combined effort of the patient, clinician, and manufacturer. To reduce corrosion, the patient should avoid eating too much salty food, should clean or change the elastics frequently, and should expose the appliance's recessed areas to air and to the flow of oral fluids to reduce localized corrosion. [(43)]

The clinician should select attachments made of alloys that are not prone to corrosion also should avoid intermetallic contacts whenever possible (especially those between different alloys), and should follow proper storage, maintenance, and sterilization procedures. Haphazard use of disinfection or thermal recycling is a common culprit. Replacement of elastics with stainless steel ligature wires or, better, use of non-corroding self-ligating brackets prevents crevice corrosion. Voids should be avoided at the bracket adhesive interface as they allow oral fluids to infiltrate and spread by capillary suction along the undercuts hence generating pits.

Manufacturers should also avoid using alloys that are too high in sulfur and carbon or too low in molybdenum or chromium. When powder metallurgy is used to make appliances, the clinician should make sure that the metal is dense enough. Finally, unnecessary weak or inadequate joints (welding, soldering, or brazing) should also be avoided.

CONCLUSION

As the oral environment during orthodontic treatment plays a pivotal role in causing biodegradation and corrosion due to changes in the properties of metal alloys this warrants special consideration regarding the biocompatibility of different metals used for orthodontic treatment.

Clinicians should be keenly aware of the degradation issues of these materials and related biocompatibility concerns. Orthodontists can be expected to respond as they have in the past by doing what is best for their patients and with the aid of orthodontic manufacturers to promote a biocompatible oral environment.

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