Orthodontic Materials and Antimicrobial Nanomaterials

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ABSTRACT
In a time when technology is present in every aspect of our lives, it is crucial to incorporate advanced solutions to protect sensitive medical data in Social Medical Systems (SMS). This study explores the need to improve security in public healthcare by using advanced technologies to strengthen the weaknesses in the growing field of Social Medical Systems. This study specifically examines the analysis of IoT-23 data using machine learning (ML) and deep learning (DL) methods, as technology and healthcare converge. The research highlights the increasing significance of technology in healthcare, specifically focusing on therevolutionary emergence of Social Medical Systems. As these interlinked networks reshape the provision of public healthcare services, security challenges such as data breaches, cyber threats, and privacy concerns become crucial barriers that require innovative solutions. The study utilizes a wide range of machine learning (ML) and deep learning (DL) techniques to examine IoT-23 data, offering a detailed comprehension of the security environment in Social Medical Systems. The chosen models comprise Support Vector Machines (SVM), Isolation Forest, Random Forest, Convolutional Neural Networks (CNN), and Autoencoder. The results and discussions focus on evaluating metrics such as accuracy, precision, recall, and F1score. These metrics provide insights into how effective each model is in identifying vulnerabilities.

1. Introduction

Orthodontics is the branch of dentistry that aims to diagnose, prevent and provide adequate treatment for facial or dental irregularities (1,2). One of these problems is the field of dental malocclusions, aiming to provide an optimal functional occlusion, as well as a harmonious facial and dental anatomy in aesthetic terms (3,4). Occlusion can be generically defined as the correct relationship between all the components involved in mastication, namely between the maxillary and mandibular dental arches when in contact (static dental occlusion) [15]. Therefore, a dental malocclusion consists of deviations considered "normal", aesthetically or functionally, normally associated with the absence of a perfect fit between the two dental arches (or, in slang, "crooked teeth"). There may be several complications, for example at the bone and/or joint level, with repercussions on speech, posture, breathing and swallowing [15]. The correction of dental malocclusions is usually carried out at the expense of orthodontic appliances (removable and/or fixed), often consisting of non-implantable metal base components, with or without complementary surgery, in order to achieve a harmonious alignment of the dental arches by application of tensions [16]. Since there are materials in contact with a biological fluid (saliva) and tissues, in an extremely complex and dynamic environment, it is essential to investigate how they behave, thus entering the field of biomaterials [17]. Orthodontic treatment should be approached multidisciplinary. Through the correction of malocclusions, orthodontics is often one of the important steps for carrying out an oral rehabilitation. Its interaction with orthognathic surgery allows the correction of skeletal-dental malformations [18, 19]. The materials used in orthodontics should produce as much tooth movement as possible, avoiding discomfort or tissue damage, in particular alveolar bone loss and root resorption. In order to achieve these assumptions, materials are tested with the aim of discovering their characteristic properties that facilitate tooth movement, therefore, orthodontic treatment. It is natural that we continue to look for materials that, due to their properties, help in clinical practice and facilitate the attainment of the proposed objectives for an orthodontic treatment [19, 20]. This work aimed to address the use of metals in orthodontics, the introduction of various alloys, their characteristics and applicability in orthodontic treatment and the antimicrobial nanomaterials were covered.

2. Oral Environment

The oral cavity performs functions associated with the reception and initiation of digestion of food and beverages, as well as phonation and diction, and the respiratory system [1, 2]. It presents as boundary structures the soft and hard palates, the lips and the cheeks, standing out structures such as the tongue and the maxillary and mandibular dental arches. The human dentition in childhood consists of 20 teeth equally distributed over the two dental arches, and between the ages of 17 and 25 they are replaced by 32 permanent teeth (in each arch: 4 incisors, 2 canines, 4 premolars and 6 molars) [1-4].

The oral environment is extremely complex and dynamic, with saliva being the fluid that bathes soft and hard tissues, with important regulatory functions. However, it is possible to find sudden and wide variations in composition, temperature and pH [4]. Several studies investigated the evolution of oral temperature over 24 h in Asians and Caucasians, obtaining variations between 5.6 and 58.5 ºC (next to the right central incisor of the upper jaw) and between 7.9 and 54 ºC (next to the first premolar of the upper jaw), although the average daily temperature remains between 33 and 37 ºC [4-7]. There were also sudden and sharp decreases or increases in temperature associated with the ingestion of cold or hot drinks or foods, respectively. The occurrence of variations of 65ºC is reported in situations of ingestion of coffee immediately after an ice cream. The ingestion of carbonated, sweet and/or acidic beverages leads to changes in saliva pH, significantly acidifying it (sometimes to pH values below 5.5), with possible consequences for tooth enamel[4-7]. Also, the presence of oral microorganisms, such as bacteria and fungi, contribute to changes in composition and pH as a result of their metabolic activity, namely when forming biofilms (bacterial plaque), which may have consequences both locally and in the characteristics of saliva [4-7]. In fact, its activity can lead to local pH values below 5, prone to the development of caries[4-7]. However, the natural presence of microorganisms has a positive impact on oral health, both against pathogens and in the chemical and physical protection of tooth enamel. Oral hygiene, in the form of mechanical brushing using toothpaste and oral elixir solutions, leads to pH changes and a decrease in the number of bacteria in this cavity, as has been recently reported in scientific articles [8-10]. The fluoride present in this type of toothpaste and elixirs also contributes to the maintenance and improvement of tooth enamel, making it more resistant to demineralization and dissolution [4]. The very action of chewing food, which in healthy individuals can reach values of around 750 N in the posterior area of the oral cavity, has an influence not only on biological tissues but also on any materials, either supported or implanted , in the dental arches [4]. Faced with these variations, as previously mentioned, saliva has a preponderant homeostatic role, so it is necessary to position its role.

Saliva is an extremely dilute solution made up of about 99% water. It is mainly produced by the submandibular glands, but the parotid, sublingual and minor salivary glands also synthesize it, although with differences in composition. Saliva has several components, namely inorganic ions (mainly Na+ , K+ , Ca2+, Mg2+, Cl- , F- , bicarbonate and phosphates), immunoglobulins, antimicrobial factors, enzymes, mucins and nitrogenous products (such as urea and ammonia), fatty acids , glucose, albumin, hormones, among others [11-14].

The concentration values of stimulated and non-stimulated saliva components, as well as the pH value, depend on several factors, such as the type of food ingested, any smoking habits , beverage intake alcohol, age and medication, gender and even the time of day (associated with circadian rhythms) [4]. For example, the pH of unstimulated saliva – that is, without food ingestion or other external stimuli that induce its production – varies according to the rate of saliva production between 5.3 (low rate) and

7.8 (peak production), although it usually remains only between 6 and 7 [4]. However, as mentioned earlier, values lower than 5.5 can occur when drinking, for example, acidic drinks[4].This brief presentation of the characteristics and functions of saliva reflects its complexity, which is further increased by the factors referred to in this section. It is, therefore, impossible to recreate this myriad of conditions in a laboratory environment, requiring a simplified mimicry, eliminating as many variables as possible.

3. Materials in orthodontics

The materials used in orthodontic treatment aim to achieve an optimal system of forces. As an optimal system of forces, what we want is that: 1) there is control, during tooth movement, of its center of rotation; 2) a correct level of stress is produced in the periodontal ligament; 3) managing to keep the stress level constant when a tooth moves from one position to another [21]. Continuous, gentle forces are intended to minimize harmful effects.

For the orthodontist, it is important to know the characteristics of the available biomaterials. What are its most relevant properties and what is its behavior when in the oral environment and under function. Thus informed, after the diagnosis, you will be able to propose, in a conscious way, which is the best material or bracket to be used in the malocclusion that presents itself. Knowing the structure and behavior of the materials will give the orthodontist the insight to better conduct the therapy, indicate or contraindicate a particular appliance and make a reliable prognosis [19].

3.1 Non-metallic materials

In addition to metals, other materials have their own clinical indications. Enumerating some of these materials [22-25]:

- Elastic modules such as latex and latex-free orthodontic elastic bandages, elastic chains, elastic thread, intermaxillary elastics, separating elastics;
- Thermoplastic containment reinforced with fiber or in a thermoplastic matrix impregnated with fiberglass;
- Myofunctional devices;
- Esthetic composite brackets;
- Aesthetic monocrystalline or polycrystalline ceramic brackets (manufactured with Al2O3 aluminum oxide);
- Aesthetic plastic brackets such as polycarbonate (introduced in the early 1970s), polyurethane, polyoxymethylene or polycarbonate reinforced with fiberglass CA-Al-silicates; - Arches coated with polyphenylene polymers;
- Aligners (polyurethane);
- Composite resins;
- Acrylics.

The literature presents the composition of various aesthetic brackets that are available on the market. In addition to the manufacturing material being of different types, there is often also the option of having or not having a metallic groove. Below, some aesthetic brackets and their constitution, inckudes:

- Reinforced composite brackets, such as Aesthetik-Line by Forestadente, or Alexander Spirit by Ormco in composite with a stainless steel slot.

- ❖ The Elegant SL (super lock) by Dentaurum are made of fiberglass-reinforced polycarbonate with a metal groove.
- ❖ RMO Esthetys in polyurethane with optional gold groove.
- ❖ Polycrystalline ceramic brackets: the Allure by GAC and the Aspire Gold Ceramic by Forestadent are polycrystalline, the latter having a gold groove. The Illusion Plus by Ortho Organizers are polycrystalline with a silver alloy groove. American Orthodontics' Virage brackets have a polycrystalline structure with a palladium-gold alloy, and RMO's LUXI II brackets also have a polycrystalline structure, with a gold groove [22-25].

Metal-reinforced polycrystalline brackets, 3M Clarity, aesthetic and self-ligating. Within the different materials that can be used in the manufacture of brackets, several combinations can still be made between them [22-25].

4. Metal alloys in orthodontics

In clinical practice, metals are rarely used in their pure form due to their poor mechanical properties. These are largely improved by the formation of metallic alloys. The alloys used in orthodontics must have good mechanical properties and high resistance to corrosion in the oral environment. Sulfuric ion is present in this medium, which combines with a large number of metals forming sulfides. However, there are few metals that form alloys with high mechanical and corrosion resistance [26, 27].

4.1 Structure of metals

The vast majority of metals are solid at room temperature. The atoms are arranged in space in ordered positions, one in relation to the other. This homologous arrangement creates defined geometric shapes, constituting the spatial grids. The most common are the face-centered and body-centered cubic and the compact hexagonal, constituting the cubic and hexagonal crystalline structures. A numerous set of atoms forms the crystalline grain and, among the grains, there are atoms that do not occupy homologous positions with those of neighboring grains forming the intergranular substance. Crystalline grains and intergranular substance are of relatively large dimensions and can be observed under a microscope [28-30].

4.2 Mechanical properties of metals

Dental materials used in orthodontic mechanics are mainly metallic, which justifies the knowledge of some of their properties. Thus, it is important to know some terminology and principles of the properties of metals in order to better understand their applicability. Typically, the mechanical properties are determined by tensile tests, these tests being suitable for ductile materials. Parallel to the addition of forces, we obtain deformation, until rupture [28-30]. From here, we can obtain various information:

Limit of proportionality

The deformations are proportional to the stresses in the specimen up to the gall point (defines the limit of proportionality).

Yield limit

Close to the gall point, it is the maximum stress that can be applied to the specimen without permanent deformation.

Yield strength

Indicates permanent deformation. In practice, it coincides with the limit of proportionality and elasticity. Limit resistance – Tension supported when breaking.

Modulus of elasticity

It is defined by the unit stress/strain ratio, up to the limit of proportionality. The higher the modulus of elasticity, the less it deforms under a given effort [28-30].

Elongation

It is measured by the permanent deformation that the specimen undergoes in the tensile test. A large elongation means the material is ductile; a small elongation means that the material can only undergo small deformations before failure. When a metal can be deformed to a high degree without breaking, it is said to be ductile, otherwise brittle. Resilience

Informs the amount of energy that a material can store when subjected to efforts up to the limit of proportionality [28-30].

Toughness

It can be evaluated by the area that lies under the stress x strain curve. If the area is large, after reaching the limit of proportionality, the material is capable of being greatly deformed before fracture. A material that fractures with difficulty is tenacious [28-30]. The hardness of a material can be defined as reflecting the penetration resistance of its surface. To evaluate the hardness of a material we define the Vickers hardness, this being one of the methods based on laboratory tests. So a hardness of 500 HV/10 means: Vickers hardness 500 using a load of 10 kgf [31, 32]. Due to the reflection of hardness on the behavior of metals and their possible applications, and also because relationships between hardness and other relevant mechanical properties can be defined, several methods have been developed for its measurement, methods that all obey the same principle, whereby a determined load is applied to a very hard indenter, which is in contact with the surface of the material to be tested [28-30, 32]. The dimensions of the penetration mark (indentation) thus left on the surface are then measured. Obviously, the smaller the indentation, the greater the hardness of the material [28-30, 32]. Tables are then prepared with the hardness values of the various materials tested. The hardness or elasticity are dependent on the composition and structure of the material, reflecting the manufacturing sequence and the geometry of the wire: section, shape, size and length of the segment [28-30, 32]. Spring effect can be defined as the elastic recovery of the material after being subjected to load. Elastic recovery is the ability of a material to return to its initial shape. It is the greater the greater its yield strength, the lower the modulus of elasticity and the greater the plastic deformation [28-30, 32].

4.3 Noble Metals

Noble metal wires are still occasionally used and although they achieve excellent properties, nowadays, due to their high cost, they are rarely used. Alloys with noble materials, such as platinum-gold-palladium or palladium-silver-copper, have no clinical relevance in orthodontics, being more used in prosthetic rehabilitation [18, 33-35].

4.4 StainlessSteel

By adding about 12% to 30% chromium to the steel, the alloy is called stainless steel. In addition to iron and chromium, other elements may be present, resulting in a wide variety of composition and properties of stainless steels. Stainless steel was introduced with the aim of replacing noble metals in orthodontic therapy. The effect of chromium causes a decrease in corrosion through the formation of a very thin, transparent and adherent layer of Cr2O3 that forms on the surface of stainless steels when exposed to an oxidizing atmosphere, such as ambient air . This protective layer acts as a barrier to prevent the diffusion of oxygen and other corrosive elements from the environment, preventing further corrosion of the alloy. If the oxide layer is disrupted by mechanical or chemical means, there is only a temporary loss of resistance to corrosion, with the formation of a new oxide layer. There are three types of stainless steel classified based on the crystalline structures formed by iron atoms: ferritic, austenitic and martensitic [33, 36-38].

Of interest to orthodontics, we have austenitic steels as they are the most corrosion-resistant alloys within the three types of stainless steel. Both AISI 302 series and AISI 304 series steels are designated as 18-8 stainless steels, based on percentages of chromium and nickel [39-41]. These are the types of steel most used in stainless steel orthodontic wires and bands due to their reasonable cost and the combination of their properties, namely:

- Great ductility and ability to be cold deformed without fracture;

- Substantial hardening during cold forming (some martensitic transformation occurs);

- Ease of welding;

- Corrosion resistance: some care must be taken into account so that this property given by the addition of chromium is not weakened [39-41].

Any surface irregularities must be removed and surfaces must be polished to prevent electrolytic corrosion. Another cause of corrosion can be contamination of stainless steel by carbon steel pliers during instrument construction [28, 42-46]. When heated above 400°C, the temperature reached during soldering, chromium is consumed to combine with carbon leading to loss of corrosion resistance. To avoid this loss, for example, titanium or niobium can be added. This has greater reactivity with carbon than chromium at the welding temperature, thus maintaining the corrosion resistance of stainless steel. A steel treated in this way constitutes a stabilized steel. They are not widely used in orthodontics due to the additional cost [28, 42-46]. Currently, in orthodontics, electric welding is increasingly used, dispensing with the use of solders and fluxes. The parts are connected together directly. Another precaution to be taken is to avoid cleaning solutions that contain chlorides, as these stainless steels are susceptible to attack by these solutions [28, 42-46]. 18-8 stainless steel is not susceptible to hardening heat treatment as carbon steel is. Its properties are achieved through the mechanical work of wire drawing to obtain the wires, so care must be taken in indirect welding. A temperature of 700 to 800ºC can recrystallize an orthodontic wire in a few seconds [28, 42-46]. Stainless steel wires can, in the situation of a fibrillar structure, reach an elasticity limit of 8000 to 10000 Kp/cm^2; in the softened condition, the elasticity limit is 3000 Kp/cm^2. The elastic capacity decreases with recrystallization at elevated temperatures. The very small diameter stainless steel wires can be braided or twisted by the manufacturer to form multifilament wires for orthodontic applications. The separated wires can be very small and have a diameter of 0.0178 mm (0.007 inches), and the wire in the final form can be round or rectangular, with dimensions between 0.406 mm and 0.635 mm (0.016 and 0.025 inches). Thus, braided or twisted wires are able to withstand large elastic deformations in bending, and apply much smaller forces for a given deflection, compared to the same unit wires, with equal cross sections [33, 36-41].

4.5 Nickel-chromium

This alloy, respectively with 80 and 20% of nickel and chromium in its composition, contains some modifiers such as carbon, manganese, silicon, phosphorus and sulphur. Also in this alloy, chromium is responsible for the high resistance to corrosion in oral environments. Nickel-chromium alloys are not susceptible to hardening heat treatment as is the case with 18-8 stainless steel. Its mechanical properties are obtained through drawing. After softening heat treatment they still have a reasonably high mechanical strength. The fact that these alloys do not lose their mechanical properties as much with welding is one of the reasons for their acceptance by orthodontists [46].

4.6 Chromium-cobalt-nickel

It comprised of 40% Co, 20% Cr, 15% Ni, 15.8% Fe, 7%Mo, 2%Mn, 0.15%C, 0.04% Be, this alloy is very similar to stainless steel in both appearance and terms. of properties. They accept conformation well, and can easily be bent, without fracturing. This alloy is also susceptible to hardening heat treatment, at around 480ºC, increasing the yield strength and decreasing elongation, which differentiates it from stainless steel [27, 32, 47].

4.7 Beta Titanium

This alloy preserves the beta allotropic form, formed at high temperatures by the addition of elements to titanium in the alloy such as molybdenum, zirconium and tin. Possessing high resistance to corrosion, this alloy accepts bends well, for making handles without fracturing. It allows direct welding (electric welding) and has a flow resistance that can reach 10,000 Kp/cm2. Although with a higher limit of elasticity and ductility than stainless steel, it has a higher cost than stainless steel [27, 48-50].

4.8 Nickel-titanium

This group of alloys includes the Nitinol alloy (55% Ni and 45% Ti), which may contain cobalt. They feature “shape memory” and “super-elasticity”. “Shape memory” means that when at a temperature between 300 and 400ºC a certain shape is given, then at room temperature different shapes can be printed, when slightly heated (between 35 and 45ºC) it tends to return to its original shape. initial form. “Super-elasticity” allows the application of nearly constant forces for long periods of time. Tensile tests to fracture show that this alloy has high ductility and low modulus of elasticity (approximately 25% of the values of stainless steel and Elgiloy alloy) which results in low intensity released forces [51-55].

5. Metal alloys – Selection and clinical application

Metals and metal alloys are the manufacturing material for a vast number of parts that are used in orthodontics. A few will be listed and a little more attention will be given to the metals used in the manufacture of micro-implants, springs, brackets, some removable appliances and archwires. Bands, tubes and buttons, metal ligatures, expansion screws for palatal disjunction, transpalatal bars, lingual bars, space maintainers, bite turbos and hooks are usually made of stainless steel. The material most commonly used in orthognathic surgery is titanium, both as a constituent of miniplates and screws [56-58].

5.1 Micro-implants

Micro-implants, currently widely used as an anchorage medium, can be made of pure titanium or contain small amounts of vanadium, iron and manganese [56-58]. It was concluded that the torsion performance of micro-implants with other metals in their constitution improves in relation to pure titanium micro-implants [59]. the composition of the AbsoAnchor micro-implants (Dentos, Korea) is cited as consisting of Ti-6Al-4V (titanium, aluminum and vanadium) [60, 61]. This Ti-6Al-4V composition, the most widely used, has lower osseointegration characteristics than pure titanium micro-implants. This factor contributes to primary rather than secondary stability, facilitating micro-implant removal [60, 61]. The researchers concluded that mouthwashes with 0.1 and 0.2% sodium fluoride solutions do not cause deterioration of the properties of these microimplants [60, 61]. Pure titanium mini-implants were manufactured with the following alloys: Ti-4Al-4V (titanium, aluminum and vanadium) and Ti-33Nb-15Ta6Zr (titanium, niobium, tantalum and zirconium), having concluded that the latter alloy presents good torsion resistance property [60-62].

5.2 Springs

Springs in orthodontics are usually made of nickel-titanium and can be closed or opened to close, open or maintain spaces. Nickel-titanium spacer springs can have forces of 100, 150 or 200g. In the literature, we found a study that demonstrates that in order to reach the distances tabulated by the manufacturers, springs have to be compressed by more than a third of their length (springs from GAC and 3M Unitek were tested) [63]. American Orthodontics springs for space closure can be either 9mm or 12mm. The springs from another commercial house, G&H, in addition to the variable length, have the intensity of the force they can produce as a variable. Depending on the manufacturer, they can vary between 50, 100, 150, 200 or 250 grams of force. In the literature, we found the relationship between length and stiffness. A shorter spring will be stiffer than a longer spring [64]. In order to try to obtain nickel-free alloys, therefore potentially less allergenic, some studies have been carried out with nickel-free alloys. Tooth movement was compared when expansion springs were applied with both the titanium-niobium-aluminum alloy and the nickel-titanium alloy. Although the magnitude of the force was smaller with the titanium-niobium-aluminium alloy, it released smooth and continuous forces, having reached the same expansion value as the nickel-titanium alloy [65]. It has been suggested that this could be an alloy to be considered as a substitute for the nickel-titanium alloy [63, 64]. We also find stainless steel closed spring and open spring available. In a comparative study of stainless steel springs and nickel-titanium springs, it can be concluded that the latter release optimal forces for tooth movement during activation when compared to stainless steel springs, due to their “shape memory” and “super-elasticity” [51-55, 64, 65].

5.3 Brackets

Metallic brackets, whether using the conventional technique or the lingual technique, and even the self-ligating ones, are usually made of austenitic stainless steel (stainless steel 17/4). Being a flat structure, like the strips, welding is usually done by autogenous or electric welding [66-68]. However, there are also brackets made of other alloys and even grooves made of metallic alloys in aesthetic brackets, as above mentioned. As an example, we can have the alloys cited in an article by Erzincanlı et al., (2020), in which the Rematitan brackets (Dentaurum) in pure titanium are referenced [69]. In another article, this one by Abdallah et al., (2019), these same brackets are referred to as being pure titanium, but the Ortho-2 (Ormco) already have the base in pure titanium but the wings in titanium alloy with aluminum and vanadium [70]. In the literature, we found a comparative studies in which the resistance to friction of three types of brackets was evaluated: ceramics with a palladium-gold slot, ceramics and stainless steel when combined with four types of archwires: stainless steel, nickel-titanium, titanium - molybdenum and titanium-molybdenum low friction [22, 71]. The smoothest surface was found between the ceramic bracket with a palladium-gold groove and the stainless steel archwire, as well as the one with the least roughness [22, 71]. These brackets showed low friction values with all archwire combinations [22, 71]. Since resistance to friction is a counter-force in tooth movement, the researchers concluded that ceramic brackets with a gold-palladium groove can be a good alternative to stainless steel brackets, in cases of sliding to close spaces [22, 71].

5.4 Removable appliances

Some of the components of removable appliances are made of metallic alloys. An orthodontic appliance has an active component and a reactive component. The active part is involved in tooth movement and the reactive part serves as anchorage. When there is reciprocal anchoring, the same component is an active and reactive member. There are three important characteristics: the moment/force ratio, the load-deflection ratio and the maximum force. To produce different types of motion the moment/force ratio has to be changed [72, 73]. Crown tilt, translation and root movements can be achieved with different ratios. It is important for the clinician to be aware that in order to produce a movement, it is rarely possible to do so by applying only one force. The moment/force to be applied must be low, in order to achieve a better control of the magnitude of the force. The reactive component must be more rigid [73, 74]. The maximum force to be applied without causing deformation is important to avoid uncontrolled activation. The design of removable appliances is also dependent on these variables. Apparatus components are normally not loaded in a simple way. Tension, compression, torsion and bending can all be part of the appliance design. As an example of some of these appliances we have the lip-bumper, the Hawley appliance, the bionator, the rapid maxillary expansion appliance, all of these with parts built in acrylic and metallic components according to the purpose of each one. As a metallic component we can find buccal arch, loops, expansion screws, springs, among others [73, 75]. The type of alloy also influences the device; stainless steel alloys are the most used. However, for example, to build a pendulum, TMA wire (beta-titanium) is used. When working with stainless steel wire, we must bear in mind that it can undergo complete annealing and recrystallization in a few seconds at temperatures between 700 and 800ºC, which is the temperature range of conventional, electric and autogenous welding (two-piece welding). of the same material hot). To minimize this effect, solders with a low melting point and a reduction in the time required for soldering should be used [73, 76]. The softening that occurs under these heating conditions can be considerably repaired by the hardening (hardening) that takes place in subsequent clinical operations, such as shaping and polishing. The increase in the elastic properties of stainless steel wires can be obtained through heat treatment at temperatures between 400ºC and 500ºC after cold deformation. This stress relieving treatment promotes the recovery stage during annealing. In this, the residual tensions introduced during the manipulation of the wire are removed allowing to stabilize the shape of the device. Residual stresses can cause fracture during clinical adjustment of the device [73, 77].

The wire section is also a relevant factor, as it can influence the released force. Round section wires are usually used and the wire diameter can vary. Blue Elgiloy wires with large diameters are used in the manufacture of appliances similar to those used in slow maxillary expansion [73]. Due to the ease of deformation, they are used to manufacture some apparatus, thermally treated to increase the yield strength and resilience values. These variations in mechanical properties with heat treatment are attributed to precipitation reactions. Appliances such as the Jones Jig or the Jasper Jumper are metallic components attached to fixed appliances [72-77].

6. Archewires

Orthodontic wires are obtained by trifilament from a cast ingot. The equiaxed crystalline grains of the molten ingot elongate to a fibrillar structure [36]. This act of deforming metals is called mechanical work. Some of the mechanical properties of metals increase with mechanical work [34]. The properties of an orthodontic archwire are a consequence of its constitution, and there are four main groups of alloys used: stainless steel, cobaltochrome-nickel, beta-titanium and nickel-titanium. Its design and handling, including heating done by both the manufacturer and the clinician, are also factors that can influence its properties [32]. They are available in various diameters and in terms of shape they can be round, square or rectangular. We can have wire sizes of 0.30 mm (0.012 in), 0.40 mm (0.016 in), 0.46 mm (0.018 in), 0.51 mm (0.020 in), 0.40 mm x 0.56 mm (0.016 in x 0.022 in), 0.48 mm x 0.64 mm (0.019 in x 0.025 in), among others [32, 34, 36].

6.1 Stainless steel arches

As previously mentioned, stainless steel is highly prone to oxidation, but the passive layer of the oxide film, formed by the oxidation of chromium, blocks the diffusion of oxygen to the inner layers. The modulus of elasticity, which determines the alloy's contribution to the release of orthodontic forces by the wire segment, is clinically important, as is the yield strength, which determines the practical limit range of elastic work [32]. Currently, stainless steel archwires are mostly used to keep the transverse dimensions of archwires stable. They are also, in many techniques, the arches of choice for closing spaces. The combination of the archwire's high rigidity with the low friction, low frictional resistance, in the archwire/slot interface of the bracket or tube facilitates sliding [78]. Due to its rigidity, it is a bow that must be worked with care, avoiding the application of excessive forces. Braided stainless steel was initially introduced for alignment and leveling in the early stages of orthodontic treatment [32]. Currently, nickel-titanium archwires being more accessible, it has been used by some clinicians in the finalization and intercuspation phase (rectangular section). Another clinical application of the stainless steel braided arch wire is post-orthodontic treatment fixed retention. Australian steel was introduced for use in Begg's technique [79]. A review of the literature reveals a lack of information regarding its physical and mechanical properties. Begg was looking for a smooth, flexible bow with high resilience to use in his technique. Available in sizes from 0.012” to 0.024” and named regular, regular+, special, special+, premium, premium+ and supreme, supreme+. Resilience increases from fair to supreme [32].

6.2 Cobalt-chromium-nickel arches

Cobalt-Chromium-Nickel Alloy Hoops are available in four heat treated states: soft, ductile, semi-resilient, and resilient. Manufacturers provide color-coded wires for clinician convenience [34]. The yarn most used is the one that underwent softening heat treatment (Elgiloy blue). Blue is the most malleable, followed by yellow (ductile), green (semi-resilient) and red (resilient) [30]. The mechanical properties of Elgiloy wires with different heat treatments are similar to those of certain stainless steel wires [80]. Due to the proximity of elastic modulus values, the orthodontic forces released by blue Elgiloy wire and stainless steel are practically equal [37]. However, blue elgiloy wire has a soft behavior compared to stainless steel due to its low yield strength [30, 32].

6.3 Beta-titanium arches

Beta-titanium alloy wires, TMA, are composed of 77.8% titanium, 11.3% molybdenum, 6.6% zirconium and 4.3% tin [32, 81]. Like stainless steel wires, nickel-titanium and pure titanium wires have different crystalline structures formed at high and low temperatures. At temperatures below 885ºC, the stable form is α-titanium, which has an HC (compact hexagonal) crystalline structure; while at high temperatures the stable phase is β-titanium, which has a BCC (body-centered cubic) structure [36]. The commercial β-titanium wires appeared around 1980, with the addition of molybdenum stabilizing the BCC structure of β-titanium at room temperature is prepared [32, 81]. The elastic modulus of β-titanium wires is intermediate between the values for stainless steel and Elgiloy wires and the values for Nitinol wire. The spring effect is much greater when compared to stainless steel wires and Elgiloy wires, but similar to that of Nitinol wires [36]. In practice this means that, for wires with the same dimensions and with the same loop dimensions, they release 1/3 of the force released by the equivalent in stainless steel or chromium-cobalt-nickel alloys [34, 81]. β-titanium wires can be cold-formed and are easily shaped and can be worked into various orthodontic configurations [32, 82]. The surface roughness of TMA wires is much greater than that of stainless steel and Elgiloy, which affects the friction between the archwire and the bracket [82, 83]. It is important to point out that the β-titanium alloy is the only alloy for orthodontic wires that does not contain nickel [36].

6.4 Nickel-titanium arches

The original Nitinol wire has predominantly a highly hardened martensitic alloy structure, with a Vickers hardness approximately equal to 430 [36]. In the 1980s these wires began to be marketed and processed as “super-elastic” [84]. These, in contrast to the originals, contain a substantial amount of austenitic NiTi structure at room temperature or at body temperature (37°C). The transformation between austenitic and martensitic of NiTi can be induced by both heat treatment and stress [84, 85]. Austenitic NiTi is formed at high temperature and low stress and martensitic NiTi is formed at low temperature and high stress. In the early 1990s, yarns with a “shape memory” effect began to be sold [84, 86]. In this, manufacturers first establish the shape when the alloy is heated to a temperature close to 480°C; when the wire is placed in the brackets, it is exposed to low temperatures (approximately body temperature) causing the arch to return to its original shape (shape memory) and promoting tooth movement [84, 86]. Studies have shown that the transformation of the martensitic to austenitic structure during heating at low temperature is complete below 37ºC, while temperatures higher than that of the oral cavity are necessary to induce the complete transformation of the austenitic structure of the NiTi alloy into superelastic wires [84, 87]. These archwires allow the transmission of smooth and constant forces during tooth movement. Its biocompatibility, low rigidity, high spring effect, super-elasticity and memory capacity are characteristics that are achieved both by its chemical composition and by thermal-mechanical treatment [34, 84]. In the mid-1990s, copper-added nickel-titanium wires (CuNiTi) appeared on the market. They are basically composed of nickel, titanium, copper and chromium [84, 88]. Due to the incorporation of copper, they have defined thermoactive properties and allow obtaining an optimal system of forces, with accentuated control of tooth movement [29]. They were introduced in the market, by Ormco Corporation, with three transition temperatures (27ºC, 35ºC and 40ºC) [84]. A comparative study was carried out between the efficiency of NiTi archwires and

NiTi with copper in the resolution of lower anterior crowding [88]. It was concluded that arch type did not affect crowding dissolution; that differences in the loading pattern of the archwires in the laboratory and the actual clinical conditions could eliminate the advantage achieved in the laboratory of the CuNiTi archwires [84, 88]. As a result of the properties of the nickel-titanium alloy, the formation of permanent folds is very difficult for the clinician (high resilience). Another disadvantage is the way in which the welding must be done [32, 84]. This alloy cannot be subjected to conventional or electrical welding, the union must be mechanical. Some roughness on the surface of the wires is also a drawback, it creates friction, increasing the treatment time [29]. There are “aesthetic” Nitinol archwires coated with Teflon (polytetrafluoroethylene). Studies show the low frictional resistance of these archwires when compared to uncoated archwires [32, 85].

7. Movement/Friction

In orthodontic treatment with fixed appliances, what we want is to create a bracket-archwire contact surface system with low friction (resistance to friction), in which the surface of a bracket allows the archwire to move easily (allows friction) [28]. Static friction is defined as the force that must be overcome to initiate tooth movement and kinetic friction as resistance to tooth movement at constant speed [89]. Given that the static and kinetic friction values generated during sliding mechanics are determined, in part, by the friction coefficients of the materials in contact, the type of metal alloy used in the orthodontic wire is an important factor to be considered. Studies have shown that stainless steel wires produce less friction than ß-titanium and nickel-titanium wires, but are less effective at greater angulations [30, 89-91]. In laboratory work, the researchers found the following results:

1) Static friction and kinetic friction are significantly influenced by the second-order angulation and by the type of orthodontic wire.

2) When the angulation increases, there is a significant increase in friction, regardless of the type of orthodontic wire considered.

3) The stainless steel archwires significantly reduced static friction, but only at the 0° angle.

4) At the highest angulations of 4° and 8°, the nickel-titanium archwires produced significantly lower static and kinetic frictional forces.

5) The ion implantation process is an effective way to reduce friction. The success of orthodontic treatment depends on the diagnosis and efficiency of the device used.

Thus, the quality of tooth movement is related to the clinical ability to control the system of forces applied to the dentition, with the need to know the inherent biological phenomena, combined with the technical information of the mechanics used, to understand the nature and results of the movement [91]. Physiologically, tension forces induce osteogenesis, while maximum pressure forces coincide with bone tissue resorption [92]. For tooth movement to occur, bone remodeling must occur around it. Bone is selectively removed from some areas and added in others [68]. The applied forces can promote tooth movement in the three planes, frontal, sagittal and transverse. According to Proffit, the dental movement of inclination is the simplest (the tooth rotates around its center of resistance). Translational motion (root apex and crown move in the same direction), rotational motion, and intrusion/extrusion are also possible [93]. Applied forces can cause tooth movement in a buccolingual direction. This movement is called torque. Many factors affect dental torque, such as the type of archwire alloy that will be used and the type of bracket where this archwire will be inserted [91]. Third-order (torque) movements are achieved using rectangular arcs. Stainless steel braided wires seem to perform better at 35°C to achieve third-order movements than Nitinol wires [94]. In order for there to be tooth movement, what is intended is a system with low friction, which is a counterforce to the movement proposed by the clinician [30]. Thus, “low-friction” archwires, “low-friction” brackets and “low-friction” ligatures were created. Also for this purpose, metal grooves were incorporated into the aesthetic brackets [28].

8. Corrosion, cytotoxicity, mutagenicity

According to Phillips' Science of Dental Materials, dental materials should be [33]:

- non-toxic;

- non-irritating, both for the oral tissue and for other tissues;

- not produce allergic reactions;

- not be mutagenic or carcinogenic.

Deep studies have evaluated parameters such as corrosion, cytotoxicity and mutagenicity of metals used in orthodontics. In cases of orthognathic surgery, these studies reveal that there may be a higher concentration of metals in the nails and hair of patients after surgery [33, 95]. The clinicians concluded that the titanium miniplates used in orthognathic surgery release elements of corrosion. The concentration of Al (aluminium), Ti (titanium) and V (vanadium) in the hair are higher in the group subjected to surgery than in the control group. Higher Ti and V concentrations were found in nails compared to the concentration of these metals in the control group. The biodegradation of nickel and chromium in stainless steel bands used in space maintainers was observed with one, two, three and four bands[33]. Even measurements with four bands showed that the values reached would not be able to cause any toxicity [33]. An evaluation of the release of nickel and chromium used in the manufacture of brackets from different manufactures was carried out [96]. Of the six study groups, five were stainless steel alloy brackets and one was a cobalt-chromium alloy with low nickel content. However, the latter was not the one with the lowest levels of nickel release [70, 96, 97]. Brackets from different manufactures showed different corrosion behavior [33]. The release of ions in stainless steel alloys without nickel and titanium was evaluated [33]. In the presence of the stainless steel alloy, the highest concentrations of ion release were found (titanium, chromium, manganese, cobalt, nickel, molybdenum, iron, copper and zinc) [33]. The nickel-free alloy released few ions. Cellular DNA was more damaged by the stainless steel alloy, followed by the nickel-free alloy. In this study, it was concluded that titanium brackets and tubes are the most biocompatible [33]. Also in an in vitro study, Pipatvadekul et al., (2022) concludes that stainless steel brackets with low presence of nickel are more biocompatible than AISI 304 stainless steel brackets [98]. However, different studies show that the amount of ions released by brackets is lower than that ingested in the normal daily diet [99, 100]. Thus, there seems to be biocompatibility and applicability of metals in orthodontic treatments [33, 95]. Also mutagenicity and cytotoxicity in orthodontic therapy seems not to be relevant [33, 95]. Although cellular alteration is verified with the placement of ceramic and metallic brackets, this alteration does not suggest malignancy [33, 95].

9. Adverse reactions

Adverse reactions resulting from the use of fixed and removable orthodontic appliances have been a matter of concern for both orthodontists and health care providers [100, 101]. Nickel has often been indicated as a metal capable of causing short- and long-term allergic reactions (type IV immune reactions) [102]. It was concluded that released ions can cause delayed allergic reactions [102]. Nickel hypersensitivity is a common problem, especially among young women, with a prevalence of 5 to 10% [102]. When compared to the oral mucosa, the skin is more sensitive to allergic reactions. The oral mucosa is less sensitive to nickel due to differences in anatomical structure [103]. Nickel is used in many orthodontic appliances and, due to its corrosion, ions can be released into the oral cavity [103]. Corrosion of the device depends on pH, composition of saliva and bacterial plaque, temperature and mechanical load. Despite this, allergies are rare. In case of hypersensitivity to nickel, nickel-free devices should be used [104]. Even in patients with proven allergy when in contact with nickel, reactions were observed, but uncommon [102]. As an example, we found in the literature a report of a case of dermatitis on the face and neck after cementation of a rapid expansion appliance (papular erythema) [105]. No intraoral reactions or symptoms were present. After removing the device, the allergy disappeared within 4 to 5 days [105]. There is also a report of a contact dermatitis reaction due to the use of a helmet for extra-oral traction in an atopic patient [106]. In order to find out how orthodontic treatment, with brackets and archwires, can influence the acquisition of images from a magnetic resonance imaging of the skull, the researchers conducted studies [107]. In this case, magnetic resonance images were obtained using different types of brackets [107]. Plastic, ceramic, titanium and stainless steel brackets were tested and it was concluded that only the latter cause significant image distortion [107]. The remaining types of orthodontic appliances only caused a minimal distortion in the quality of the images [107].

10. Fluoride application during orthodontic treatment

We found in the literature several studies on the application of fluorides, in mouthwashes or in gel, during orthodontic treatment [108]. Knowing that with the cementation of orthodontic appliances we increase the level of demand to maintain good oral hygiene, since there is a greater accumulation of bacterial plaque [109-111], it is frequent to oral hygiene routines, often with fluoride application [112, 113]. In the literature, we found a correlation between orthodontic treatment and the appearance of white spot lesions on the enamel caused by decalcification [114-117]. However, as a result of some studies, we found a decrease in the mechanical properties of, for example, beta titanium and stainless steel archwires when exposed to fluoride prophylactic agents, contributing to an increase in orthodontic treatment time [45, 118, 119]. This conclusion was also found by Kaur et al., (2022), in a study with nickel-titanium alloy archwires [120]. Two studies, on the effect of fluorine application on titanium alloys, shows changes at various levels. Morphological variations such as increased roughness with adverse effects on the sliding mechanism, effects on the super-elasticity plateau, or reduced strength of the arches [53, 85]. In the study by Deery et al., (2019), of different mouthwash elixirs, the one containing the most chlorhexidine was the one that showed the greatest release of metal ions in the presence of stainless steel orthodontic appliances [121]. In contrast, however, there are studies that demonstrate the importance of applying fluoride varnish close to the brackets, avoiding the demineralization of this area [122, 123]. Sonesson and Twetman (2023) shows the advantages of using a toothpaste with 5000 ppm of fluoride to control a small caries lesion caused by the use of orthodontic bands [124].

Due to the increased risk of caries during treatment, several prophylactic measures should be indicated to patients, including: good oral hygiene, topical application of fluoride, use of chlorhexidine and sealing of fissures. The researchers recommend a specific diagnostic approach to present valid preventive measures [91, 125-127]. The application of fluoride during orthodontic treatment has its pros and cons. If, on the one hand, we know that the increased retention of bacterial plaque, due to the placement of the device, increases the risk of caries and the appearance of white lesions of demineralization, implying preventive measures which include the topical application of fluoridated products [91, 127]. On the other hand, it has been demonstrated an increase in the release of ions, corrosion, with the application of topical fluorine. Characteristics of brackets and archwires also change with their application [91].

11. Covered archwires

The first aesthetic wires were composed of a metal alloy and covered with a layer of Teflon (polytetrafluoroethylene) or epoxy resin, similar in color to teeth or polyethylene [28]. Ceramic brackets or transparent composites meet the demand for esthetic brackets. To match these supports, Coated Ni-Ti wires are resin-modified. The use of polymeric coatings on orthodontic wires can provide, in addition to aesthetically desired solutions, a reduction in surface alterations, favoring sliding mechanics. In orthodontics, wires coated with epoxy resin, Teflon and polyethylene have been found [128]. The coatings used on metallic wires have low resistance in the oral environment, which causes flaws and cracks in the coating, exposing the metallic wire and impairing aesthetics [28]. The changes in the coating and color of the thread has been aslo recorded. Certain factors influence the mechanical properties of orthodontic wires, mainly in sliding mechanics [128]. These factors basically depend on the characteristics, shape and nature of the brackets; of the inherent characteristics of the wire and the type of ligature, and, finally, of the oral environment, since not only the dental biofilm, but also the presence of saliva, can lead to corrosion and influence the intensity of the orthodontic force and, consequently, , tooth movement [28, 128]. Wires covered by epoxy resin present good aesthetics, resist deformation, maintain superelastic characteristics, low friction; but it is necessary to perfect the technique so that the resin does not come loose from the thread [28]. Examination the properties of coated metallic wires, concluded that approximately 25% of the wire coverage was lost during use, significantly impairing aesthetics [28, 128]. Polytetrafluoroethylene coatings - PTFE or Teflon, is a chemically inert fluorinated polymer, with high oxidative and thermal resistance, with low surface tension. However, the literature lacks more research on its use as a covering for orthodontic arches [128].

Another important factor is that as the diameter of the coated metallic wires increases with the coating, the wire deflection is smaller when compared to the conventional metallic wire. [28]. The wires during orthodontic movement must promote appropriate forces to the teeth, and present satisfactory properties in addition to meeting the aesthetic needs [128]. An example of coated wire is the aesthetic superelastic Coated Ni-Ti wire manufactured by Dental Morelli LTDA [128]. Coating Composition: Epoxy resin resin. The wires that have the epoxy resin coating undergo a coating process by depositing that resin on the base of the wire, with a thickness of 0.002 inch, which provides strong adhesion between the coating and the inner wire. (Source: Product packaging/ manufacturer) [28].

12. Archwires Properties

Orthodontic wires have unique characteristics, properties and applications, which allow their use in the most diverse cases. Through studies of their properties, orthodontists must find those that best adapt to the clinical cases they are working on. New interactions between threads will allow new techniques to be created and better applied. In this way, it is essential that its indications and contraindications are known, so that the result of a treatment plan can bring the patient a better quality of life and the professional, the same clinical chair time and shorter treatment time [129-131].

12.1 Friction

Friction force is the result of perpendicular pressure between two opposing surfaces, in this case, wire and bracket. This force is parallel to the surfaces and the direction is always opposite to the displacement [28, 128]. Friction is one of the characteristics that act directly on orthodontic movement, when the friction force between the wire and the bracket is high, it results in an effective decrease in tooth movement. It is not possible to eliminate friction during orthodontic movement, but it is possible to minimize the effects by improving the characteristics of the wire/bracket set, thus reducing the magnitude of forces applied to the teeth [28, 128]. The friction can be defined as the magnitude contrary to the movement of a body in tangential relation to the surface of another, acting in the opposite direction to the displacement tendency of the same [28, 128]. Despite this, without friction, many movements would not be possible, such as correction of teeth with rotations, verticalization of inclined teeth and preparation of units for anchorage, that is, grouping of stabilized teeth that help the orthodontic movement of one or more teeth. teeth [28, 128]. One of the important mechanical properties is the friction that orthodontic wire alloys cause in sliding mechanics. The different types of coverage change some properties of the yarn, such as friction and friction. It is also observed that the Teflon coating completely prevents the corrosion process of the wire [28, 128]. throughout its use in the oral cavity, when compared to conventional Ni-Ti wires. And FRP wires showed up to 40% less friction when compared to other materials. The friction coefficients and wear rates of FRP wires are better than those of used metal alloys [28, 128].

12.2 Resistance in an acid medium

The thread must present biocompatibility with oral tissues [28, 128]. In the mouth there is both a dry and a wet medium. The dry environment occurs when saliva is expelled from the contact surfaces between bracket and wire, leaving a “dry” surface. A humid environment is one in which saliva surrounds surfaces [28, 128].

12.3 Stress relaxation

Tension relaxation concerns maximum elasticity and flexibility, the range of activation and deflection of the wire, and how much the wire can be worked. Higher relaxation values require more activations and more wire changes. When we press the orthodontic wire into the bracket slot with the aim of correcting a misaligned tooth, this act of bending the wire will cause an increase in stress. When the wire quickly relaxes, the tension loses the strength necessary for orthodontic movement [132-134].

12.4 Surface characteristics

The surface characteristics of the wires, as well as their topography, are extremely important, since they determine the area of contact with the oral tissues and with the orthodontic accessories. It can affect aesthetics and also your orthodontic movement. Defects on the surface interfere with friction and can directly affect the sliding mechanics, they can also trigger corrosion, bacterial plaque accumulation and even the release of undesirable ions in the oral cavity. Knowing the surface characteristics is extremely important to evaluate the other properties [82, 131, 135, 136].

12.5 Elasticity

Another property is elasticity, the ability of a body to undergo pressure or tension without permanent deformation occurring. It is used in the vast majority of our devices. Three are the basic elastic properties: stiffness, resistance and the elastic work interval [80, 137, 138].

Flexibility – Elasticity: also refers to the maximum elastic deflection, maximum flexibility [36]. It is the deformation that occurs in a wire when it is deformed to its elastic limit or proportional limit [36].

Several studies tested the elastic properties of orthodontic wires of different thicknesses and different manufacturers with the objective of helping orthodontists in choosing the appropriate wire for carrying out their work. Usually the choice is made based on the reputation of the manufacturers and the highest degree of resilience, without prior knowledge of test results to prove their performance. Given the diversity of results, they suggested that important mechanical properties for yarn performance should be printed on their packaging [36, 37, 51, 139]. The results of deep studies showed a modulus of elasticity 20% lower than the general values usually reported in the literature, not suffering alteration by the release of tensions used in the clinic. The decrease in modulus is attributed to the rigorous “cold work” during manufacturing that induces changes in the crystalline lattice that can modify the mechanical properties [140-142]. Wires with very high heat treatment showed higher modulus, consistent with general values, which validates the results of untreated wires. If the module is smaller, according to several studies, it would be necessary to proportionally increase the force for an ideal activation [140-142].

12.6 Toughness

Toughness is the property that informs about the difficulty of breaking a structure, that is, the energy required to fracture a material. Fragility: it is the opposite of tenacity, that is, a brittle material tends to fracture close to its proportionality limit [143]. A typical example of a fragile material is glass. In general, materials with very high mechanical strength are brittle. One of the goals of materials engineering is the development of materials with high levels of mechanical strength associated with high levels of fracture toughness [143]. Conventional Yield Limit: These are small permanent deformations that can be observed in practice at any stress when metals are tested. The conventional yield limit is the maximum stress associated with the maximum deformation that can be tolerated for the metal to perform well during use and is determined from a tensile test. This conventional value is usually determined from 0.2% plastic strain. [143]

By the definition of the Farrier's and Horseman's Dictionary (2018), wire is understood as: “A very flexible piece of metal, with a circular section, with a very small diameter in relation to its length” . Of great importance is its ability to transmit force along its length [144]. Currently there are numerous metal alloys that are offered in the form of wires and are used in orthodontics. They are called orthodontic wires, being the main component of therapy with fixed appliances. The orthodontist can determine the shape of the wire arch according to predetermined diagrams so that it exerts force on brackets fixed on dental crowns and promotes movement [28, 128].Once activated, orthodontic wires have the ability to accumulate mechanical forces and then transmit them to the teeth, through the bracket or band, in all three planes of space to promote, over time, a controlled displacement of the dental element or set of teeth. The wire can also, in addition to promoting tooth movement, ensure anchorage, by opposing forces that would cause future displacements. In this way, the wire also has the function of stabilizing the arch, preventing unwanted movements [28, 128]. It is up to the professional, when selecting the most convenient wire for a given situation, to choose the one that presents greater or lesser deformation, small or greater activation capacity, lesser or greater stiffness, less or more resistance [28, 128].

According to Ciavarella et al., (2023), the mechanical and physical properties of materials used in orthodontics show great changes under variable handling conditions [23]. For this reason, for a correct use of these materials in the construction of orthodontic appliances, the professional must know them in more detail and also their respective properties. With regard to wires, you should become familiar with their mechanical properties [23]. With that, the orthodontist will provide greater benefit to the treatment obtaining better results [23].

To know an orthodontic wire, there are three important characteristics to be considered: rigidity, resistance and its working limit, that is, maximum flexibility [23]. Stiffness is defined by the amount of force accumulated for each millimeter of wire activation [145]. This characteristic is not interesting for the initial phases of orthodontic treatment. For this reason, the reduction of wire gauges becomes essential to reduce their stiffness. For this reason, conventional treatment with steel wires includes a sequence of wires that is progressively thicker, so that, when the teeth are very misaligned and/or uneven, the wire can be deflected more, with low release of force and without suffering damage. a permanent deformation [23, 145]. The resistance is related to the maximum tension that the wire can withstand before breaking [23, 145]. In the drawing process, when the wire diameter is reduced, the tensile strength increases. He also concluded that high temperatures in the welding process reduced the tensile strength, hardness and proportionality limit in the wires, and among these properties, the proportionality limit was the most affected. Flexibility is the property presented by certain bodies of being susceptible to large elastic deformations when they are under the action of small magnitude stresses, depending a lot on the shape of the material structure [23, 145].

Given the variety of orthodontic wires available on the market, knowledge of their mechanical properties, combined with the stage of orthodontic treatment, facilitates the choice for their indication. The technological evolution of the manufacture of wires and the development of new orthodontic techniques strive to improve the quality of the alloys, in order to make them biologically more compatible with respect to the teeth and supporting tissues [146]. In fact, several properties and different characteristics are considered when choosing the appropriate orthodontic archwire. Among them are: shape memory, low rigidity, high formability, biocompatibility, low surface friction, weldability, resilience and aesthetics, described in detail below; however, no orthodontic wire has all the characteristics simultaneously in a satisfactory way [23, 145, 146].

12.7 Flexion

In the bending test, it is possible to quantify the energy released during loading and unloading of orthodontic wires. The wires, when activated, store some energy (resilience) and, during unloading, they transmit part of this energy in the form of work to move the teeth [38]. Sometimes the energy applied to bend the wire is not the same as the energy released. For example, in wire made of stainless steel and other metals, practically all the energy stored during activation in the elastic regime is released in the form of work. The paths taken in loading and unloading in the elastic region are the same [23, 38, 145, 146]. For NiTi alloy wires, the path of the unloading curve is not the same as the loading curve; the energy released (unloading) in the form of work to move the tooth is significantly less than the energy consumed in activation (loading). This difference in path during loading and unloading is called hysteresis [23, 38, 145, 146].

13. Turning toward nanoparticles

13.1 Background

Orthodontic treatments have as objectives the search for functional and aesthetic excellence aiming at the harmonization of the dento-maxillo-facial complex, through diagnosis, planning and an appropriate mechanical apparatus consisting of brackets, bands, wires, composite resins, among others [23, 38, 145, 146]. Despite their role in orthodontic movement, fixed orthodontic appliances provide patients with a greater risk of gingivitis, white spot lesions and caries due to the adhesion and accumulation of pathogenic bacteria from biofilms around orthodontic brackets, wires and bands [38] In addition, this accumulation of biofilms on the surfaces of orthodontic wires and brackets increases their surface roughness and, consequently, increases friction, which makes orthodontic mechanics more difficult, in addition to causing corrosion [28, 128]. Nevertheless, common prophylactic measures in orthodontic patients against caries, gingival disease and the accumulation of biofilms such as a good oral hygiene regime, new therapeutic alternatives combined with biotechnology are being proposed [28, 128]. Nanohnology has contributed lately through the use of orthodontic composites in bonding brackets, doped with silica and silver nanoparticles[9], deposition of silver nanoparticles on steel orthodontic wires and nickel/titanium wires and steel, with satisfactory results [38]. Another antimicrobial widely used and recognized for several decades is titanium dioxide, which has its means of interaction with microorganisms probably due to the phenomenon of photocatalysis, and being non-toxic [38]. An alternative to inhibit pathogenic bacteria that cause biofilms is the deposition of thin films of titanium dioxide doped with silver, through the sol-gel process, deposited on bands, wires and orthodontic brackets. The sol-gel process presents the best prospects for the development of biocide coatings, with good adhesion, minimal drying problems, low densification temperatures and good cost-effectiveness [18, 38].

Currently, nanotechnology is present in several areas of research such as Physics, Chemistry, Electronics, Medicine, Computer Science, Biology and Engineering, where it has allowed the development of new materials and techniques that are much more efficient than those already known. In the areas of health, nanotechnology has found fertile ground in Dentistry. Its application is being widely tested in several specialties and especially in Orthodontics, from surface coatings to the improvement of nanoparticulate composite materials, using cements and polymers as matrix, and in rinsing solutions [147].

13.2 Application of nanotechnology in dentistry

The term “nanodentistry” was coined by R.A. Freitas Jr., in 2000, where some visions were developed using nanorobots for orthodontics, which although they were far-fetched ideas at the time, and currently, are gradually being implemented in practice [147]. Currently, nanotechnology applications in dentistry are present in several areas such as diagnosis (use of nano-biosensors), preventive dentistry (nanoparticles in oral care), endodontics (incorporation of bioceramic nanoparticles, such as bioglass, zirconia and glass-ceramics in endodontic sealers) , conservative and aesthetic dentistry (restorations with nanoresins), periodontics, implant and regenerative dentistry (nanoparticles incorporated into grafts) [147, 148]. Combating bacterial infections has been done by nanoparticles of metals, metal oxides and others that have antibacterial, anti-inflammatory and remineralizing properties [147, 148].

In the specialty of Orthodontics, several studies have focused on the efficiency of nanoparticles inserted into orthodontic materials in the form of thin films, deposited on wires, brackets and orthodontic bands, as well as diluted in cements and adhesives with multiple purposes. However, the preservation of the mechanical properties of materials such as adhesion strength at the orthodontic device/tooth interface, reduction of the coefficient of friction and antimicrobial properties are indispensable [147, 148].

Nanoparticles have been considered in recent years as a viable alternative to antibiotics and seem to have high potential to solve the problem of the emergence of bacterial resistance to multiple drugs [149]. Nanoparticulate metals are being widely studied due to their physicochemical characteristics, including catalytic activity, optical properties, electronic and magnetic properties, and antimicrobial activity [149-151]. Among the nanoparticulate metals, it is possible to mention the silver nanoparticles that have excellent antimicrobial activities [152, 153]. However, in the same way that the use of NPs is advantageous, they can also become dangerous. Research on NPs is increasingly studied and safety concerns must be discussed and questioned, since nanoparticles are harmful to bacteria and not to the organism [147, 148].

14. Oral microbiome

The oral environment allows the colonization of diverse microbial species with nutrient flow, high humidity and variable oxygen concentrations. The existence of hard and soft tissues enables greater adherence and interaction of microorganisms with various host cells [154].

In recent years, many works have reported the behavior of bacteria-surface interactions. Thinking about the initial adhesion of microorganisms, it is necessary to consider the movement of bacteria towards a material surface that occurs through the effects of physical forces, such as Brownian diffusion, gravitational sedimentation and hydrodynamic forces and also by their own motility [154, 155] . The accumulation of biofilms around orthodontic brackets reduces the pH in these places, inducing the demineralization of dental enamel, in addition to promoting an increase in orthodontic frictional forces, corrosion of materials due to its accumulation on metallic surfaces of wires and brackets [154, 156].

Superficial demineralization creates pores between the enamel prisms, making the surface rough, altering the refractive index and reflection of the enamel and, consequently, causing the loss of its surface shine [154, 157]. In addition to the problems mentioned above, some microorganisms when adhered to the surface of the teeth cause periodontal disease. Periodontitis causes progressive loss of alveolar bone triggering excessive mobility and subsequent tooth loss [154, 157]. Previous studies have demonstrated the exacerbation of periodontal disease linked to Staphylococcus aureus in patients who have these opportunistic diseases in the oral cavity and gram-positive bacteria, highly adaptable and resistant to several antibiotics [154, 156-159].

Bacteria are single-celled organisms and the main component of cellular life on Earth, one of the oldest and structurally simple forms of life. They are found in all places and surfaces, cannot be seen with the naked eye due to the size that varies from 0.2 to 1.5µm in diameter and 1 to 10µm in length and are characterized by a prokaryotic cellular organization, lacking a nucleus defined [160]. Their nucleus is dispersed in the cytoplasm, which contributes to their high mutagenicity. They can live singly or in colonies [161]. According to morphology, they are mainly classified into cocci, spirilla bacilli, forming different sizes and arrangements [160, 161].

S. aureus is one of the most common bacteria in clinical practice that often adheres to human tissues, multiplying, creating colonies and consequently a reservoir of bacteria conducive to invading our body causing different types of infections [162, 163]. After entering the body, S. aureus can contaminate the blood, leading to more serious infections, which can reach any organ, such as the heart, in the case of the dreaded endocarditis. Other possible infections are pneumonia, meningitis, severe sepsis, toxic shock syndrome, and others [163, 164]. The bacterium S. aureus was chosen in many works due to its high virulence and resistance to antibiotics [162, 163].

15. Antimicrobial nanomaterials

It can be seen currently, and on an emergency basis, a constant search for intelligent technology to develop materials and surfaces capable of combating pathogenic microorganisms are present in our daily lives. The need to create surfaces that promote the destruction of such organisms and prevent bacterial infections becomes increasingly urgent, since the adhesion and growth of biofilms can be inhibited at an early stage [165-168]. Once the biofilm is formed, the fight against bacteria is made difficult. Once irreversibly established, there is greater difficulty in combating the bacteria, making them resistant to the antibiotic [165-168]. Antibiotic resistance is explained by the inability of agents to penetrate deeper and exert their effects on the entire biofilm, since their action is limited to the upper layer with less effectiveness on bacteria located deeper within the microcolonies [165-168]. Bionanotechnology has enabled the creation of new preventive strategies in the control and management of bacterial biofilms in the oral environment. Different types of metallic and ceramic nanomaterials such as copper, zinc, titanium, magnesium, gold, silver, titanium dioxide, respectively, in addition to Ag/TiO_2 nanocomposites, have been shown to be effective against bacteria, viruses and other microorganisms [169-176].

15.1 Titanium dioxide (TiO_2) nanoparticles

The chemical element titanium is the ninth most abundant element on Earth, but it is not found pure, but as a mineral: rutile (TiO_2) or ilmenite ($FeTiO_3$). It was first reported in 1791 by the English chemist and metallurgist William Gregor (1761-1817), and in 1794, titanium was rediscovered by Martin Heinrich Klaproth, when performing the extraction of the mineral rutile, one of the crystalline forms of titanium dioxide [174, 176, 177]. Titanium dioxide (TiO_2) is a semiconductor whose main crystalline phases are rutile, anatase and bruchite. Rutile is the most thermodynamically stable phase at high temperatures, while anatase and brukite are metastable and can convert to rutile [178, 179]. Anatase is the most photoactive phase of TiO_2, which generates the greatest amount of electron/hole pairs under ultraviolet (UV) radiation [148, 174, 177].

Since the discovery of electrochemical photolysis of water with a TiO_2 electrode by Fukushima and Honda in 1972, scientific and technological interest in this material has grown enormously, making TiO_2 the most studied and used photo catalyst for various applications [174]. The properties that justify this fact are super hydrophilicity, strong oxidizing power for the decomposition of organic pollutants, chemical stability, non-toxicity, low cost, transparency in the visible region and long durability [176]. The versatility of TiO_2 can be seen in some examples of the various fields of application with the aim of improving people's quality of life [176]. Different applications arise together with the appearance of new physical and chemical properties resulting from the reduction to the nano metric scale of the material, such as obtaining self-cleaning and hydrophobic surfaces, anticorrosive, antimicrobial and others [148, 176, 179].

The self-cleaning and hydrophobic properties are related to the ability of TiO2 nanoparticles to acquire a photoinduced superhydrophilic behavior [176, 180], that is, under excitation with adequate light it undergoes a process called photocatalysis, causing the dirt molecules to be decomposed and consequently carried away with the application of a water flow [148, 180]. In the form of thin films and even the incorporation of nanoparticles into other films, TiO2 behaves as a protector of alloys against corrosion [148]. The antimicrobial property of titanium dioxide nanoparticles is also related to the photocatalysis process, where reactive oxygen species (ROS) are produced when exposed to light, causing the death of microorganisms [148, 176, 177, 181].

15.2 Silver nanoparticles (AgNps)

Silver is a monovalent noble metal belonging to the group of transition metals, with atomic number 47 and atomic weight of 107.87u. Its melting temperature is 961.78°C and the boiling temperature is 2162°C, presenting the highest thermal and electrical conductivity of all metals [152, 174, 182]. Silver has very high malleability and ductility and is found in nature in a metallic state, in alloys with gold and other metals and in ores, such as argentite and cerargirite [183]. However, most of the silver produced is a by-product of copper, gold, zinc and lead extraction [177]. Mexico is still the largest producer of silver, followed by Peru and China [148]. Nanoparticulate metals are being widely studied due to their physicochemical characteristics including catalytic activity, optical properties, electronic and magnetic properties and antimicrobial activity [176]. Among the metals used, silver particles were used as a broad-spectrum antiseptic and antimicrobial against gram-positive and gram-negative bacteria due to their low cytotoxicity [148, 152]. The use of silver nanoparticles in Dentistry and Medicine has been encouraged, as they have a broad-spectrum antimicrobial effect when used at low concentrations and because they do not lead to the development of resistant bacterial strains [148, 176]. Although the antimicrobial effect of silver nanoparticles has been widely described, its mechanism of action is not fully understood [183]. The different mechanisms of action of Ag nanoparticles on microorganisms have been described by several authors [152, 182, 183]. Among the mechanisms are changes in the cell wall and cytoplasm of microorganisms, changes in membrane permeability and respiration, morphological changes and separation of the cytoplasmic membrane from the cell wall, plasmolysis, inhibition of bacterial DNA replication and changes in ATP levels [174, 176, 182].

There are several methods to produce AgNPs and basically they can be divided based on four approaches: chemical, physical, photochemical and biological methods such as chemical reduction, laser ablation, reduction of green photosynthesis using plants such as algae [152, 177, 182]. Chemical methods of synthesis of AgNPs can be considered as standards, for example, reduction of AgNO3[152, 174, 183]. It is noteworthy that AgNps have high surface energy being thermodynamically unstable and, consequently, tend to form aggregates and propensity for growth [176, 183]. Thus, studies on the synthesis and functionalization of AgNPs are the subject of continuous study by several researchers, with the aim of generating particles with greater chemical stability [148, 152, 174, 182, 183].

15.3 Ag/TiO2 nanocomposite films

The growing interest in the modification of a TiO2 ceramic and semiconductor matrix with the insertion of Ag nanostructures is due to the combination of properties of both compounds, increasing the potential application of TiO2 in several nanotechnological fields [174, 184, 185]. Among the various areas of application, photocatalysis, bacterial inhibition and self-cleaning coatings stand out [148, 184, 186]. A qualitative and visual test were performed to verify a possible antimicrobial or bactericidal action presented by thin films of TiO2 and Ag/TiO2 on substrates of 316L steel and glass, using bacteria Escherichia coli (E .coli). [174, 177, 184, 187-189]. It was observed that there is antimicrobial activity when using UV-A radiation both in TiO2 films and also in Ag/TiO2 films treated at 400°C and the scope of this activity increases proportionally to the number of coatings [176, 177]. The bacteriostatic activity of TiO2 and Ag+ against S. aureus strains was tested using the minimum inhibitory concentration (MIC) assay, concluding that the species can cause effects on bacterial membrane permeability, reduce protein solubility by inhibition of the synthesis of nucleic acids, consequently, inhibiting the growth of S. aureus [148, 184, 185].

16. Biocompatibility and nanotoxicity of nanomaterials

Previous studies have shown that although the use of NPs in all fields of healthcare and including orthodontics may offer new possibilities, information on long-term performance is lacking and therefore requires further investigation [174, 177]. Due to their small size, nanoparticles can reach regions of complex anatomy, since only particles smaller than 1nm and with a minimum concentration of 10 mg/mL have cytotoxic effects [148, 186]. However, improved physicochemical characteristics such as nanometer size, large surface-to-mass ratio, and increased chemical reactivity may produce superior antimicrobial effects as a result of increased interaction with microbial cells [176, 177].

It is important to mention the ability of NPs to have antimicrobial activity even after a long period of action [177, 186] and also effects of the generation of reactive oxygen species (ROS), together with oxidative stress that play an important role in this context of toxicity [176, 179]. Despite the rapid progress and early acceptance of nanobiotechnology, adverse health effects due to prolonged exposure to various concentration levels in humans have not yet been established, not even regarding the environmental impact that NPs may promote [176, 179].

2. Conclusion

Various types of metallic appliances are used for the treatment of malocclusions. These appliances are placed in the oral environment under stress of various orders, masticatory forces, appliance activation, temperature fluctuations, varieties of food ingested and saliva are just a few. It becomes relevant to know the behavior of these devices, therefore, of the metal alloys that constitute them, when under these conditions. Having several options to choose from to reach a certain result of the proposed treatment, it becomes difficult to define a single line of action. Different techniques use different materials and/or different sequences of materials. Clinical experience in collaboration with studies and clinical trials help in making informed decisions. As a common core to all techniques, we know that the nanomaterials used must be biocompatible and that, ideally, during orthodontic treatment, we should favor the use of nanomaterials with good resistance to corrosion and bacterian infection. In this way, the creation of new materials and surface coatings that prevent bacterial adhesion and the establishment of pathogenic biofilms become essential to combat such microorganisms.

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