Review Article:

A Review of the Requirements and Hazards of Toxic Metals From Orthodontic Wires

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Article info:
Received: 02 Aug 2020
Accepted: 25 Aug 2020

Keywords:
Orthodontic appliances, Orthodontic wires, Metal ions release, Toxic metals, Saliva, Orthodontic treatment

ABSTRACT

Background: Orthodontics is a part of dentistry that comprises preventive methods and correction of dental irregularities that need to be repositioned by functional and mechanical tools to provide an ideal occlusion and a beautiful face for patients. There are currently four metal archwires used in orthodontic treatment: stainless steel alloy, cobalt-chromium alloy, nickel-titanium alloy, and beta-titanium alloy. Toxic effects generally occur when the body's tissues are exposed to sufficient amounts of metal ions for long periods.

Objectives: The present study briefly reviews the requirements and hazards of toxic metals from orthodontic wires.

Methods: This study is a review of the available reliable sources and reference documents and scientific-research articles published in the international journals and databases with the focus on the requirements and hazards of toxic metals from orthodontic wires.

Results: Optimal characteristics of an archwire for optimal performance are spring return, ductility, modulus of elasticity, biocompatibility, and low friction. The release of metal ions from dental alloys is due to local and systematic chemicals, mutagenic, immunogenic, and toxic effects.

Conclusion: Today, most orthodontic brackets, braces, and archwires are made of stainless steel and nickel-titanium, all of which contain varying amounts of nickel, chromium, and cobalt ions. Increasing the amount of ions released from orthodontic alloys causes a cytotoxic state for the body. Although orthodontic alloys contain anti-corrosion agents, they are prone to corrosion in dynamic oral environments.

Citation Babaei Hatkehlouei M, Dadgar S, Shokrzadeh M, Mousavi J, Sobouti F. A Review of the Requirements and Hazards of Toxic Metals From Orthodontic Wires. Pharmaceutical and Biomedical Research. 2020; 6(4):251-260. http://dx.doi.org/10.18502/pbr.v6i4.5111

doi: http://dx.doi.org/10.18502/pbr.v6i4.5111

Introduction

Malocclusion is the abnormal position of the teeth or jaw and it is a deviation from growth and development that affects the mating of teeth, the ability to clean teeth, gum health, intellectual growth, and learning to speak.

Both heredity and environment play important roles in the development of malocclusion. The shape and size of the face, jaw, and teeth are often inherited. Environmental factors that cause malocclusion are many and most of them can be controlled by a pediatric dentist. The most important is decay or an early loss of deciduous teeth [1].

Crowding

Dental malformations are a deviation from the natural growth and development and parting from the natural standards of beauty in a society that affect the muscles and bones in adolescence and youth. Irregular teeth can cause psychological and social problems due to the effects they have on a person's beauty and significantly affect a person's quality of life [2, 3]. Dental dysfunction, such as chewing and talking [4], as well as increasing the risk of trauma [5] and periodontal problems [6] are other issues that occur with crowding.

According to studies in the United States, up to 30% of people have a normal occlusion, and class I abnormalities are more common than other abnormalities (50% to 55%). The prevalence of class II abnormalities is about 15% and class III is less than 1% [7]. According to Mangouri and Mustafa, the highest prevalence of class II anomalies is among whites with Northern European roots. Class III anomalies, on the other hand, are most prevalent among Orientals (3% to 5% in Japan, 2% in China, and another 2% to 3%, who have a false three-grade class). In other words, due to the inconsistencies, the mandible deviates towards the anterior crossbite [8]. The study of Biria, Islami, and Rahmani (2012), which was performed on 3- to 5-year-old children in Tehran, also showed that the relationship between one tooth class was the most frequent (77.3%) and the third-class was the least common (9.4%) [9].

Reduction of the second-class relationship (13.3%) from the age of 3 to 5 years has also been reported in connection with the end of the effect of some environmental factors, such as finger sucking until the age of 5. On the other hand, the remains of the corpses of the ancients show that the prevalence of the anomaly is now many times higher than it was only a few hundred years ago and until recently tooth irregularities have been almost an unusual problem that, of course, was not known. According to some researchers, reducing the progressive size of the jaws following a change in diet can cause crowding [7].

Irregular teeth are one of the main reasons for patients to refer to orthodontic treatment and can cause an inability to observe hygiene, gum and periodontal disease, and loss of beauty [7]. Therefore, by diagnosing the lack of space in time and performing special preventive treatments, a severe anomaly can be prevented in the future. To plan for such treatments, it is first necessary to have statistical data on the people in need of treatment [10]. The term serial eruption, first coined by Kjellgren (1929) from Sweden and then Hotz (1970) from Germany. It is also called the guided method or vegetative guide by Little and Wilson's and is considered an intermediate process to help correct tooth and jaw size disorders [11].

By performing this treatment process, the cost and duration of treatment with different types of orthodontic appliances will be reduced; the patient will be treated more easily; the possible problems of the next treatments will be reduced and time will be saved. The vegetative guidance of the teeth, during the successive growth of the teeth, also leads to the correct placement of the periodontal fibers during their formation. As a result, orthodontic treatment is more stable and reduces the return of crowding after treatment [10]. Greiber coined the terms hereditary and peripheral crowding, in which patients with hereditary crowding (who have severe differences in tooth size and arch size) are treated with successive tooth eruptions. Patients with peripheral crowding may, however, be able to be treated without tooth extraction [10]. In a study conducted by the United States Public Health Organization on 8000 samples of 6 to 11 years old, 40% of people had crowding problems, and the prevalence of people who could be treated by having their teeth extracted is estimated at 16% [12].

Many factors have been reported as the causes of crowding, such as large tooth size, mandibular growth, the early loss of deciduous molars, muscles outside and around the mouth, longitudinal axis position of the teeth, or a combination of the above reasons. One of the factors mentioned as an etiological factor in anterior teeth crowding is the dental dimension factor, which was first introduced in a series of studies by Peck in 1972 [13]. Since then, a lot of research studies have been done on the relationship between tooth size and crowding. Some of these studies consider tooth size to be the most important factor in the emergence of crowding [13, 14].

Orthodontic science

Orthodontics is a Greek word. “Ortho” means straight and “dontics” means teeth so Orthodontics means aligning teeth with incorrect position [15]. Orthodontics is a branch of dentistry that studies and monitors the direct growth and development of teeth and related anatomical structures, from birth to dental development. Orthodontics includes preventive methods and correction of dental irregularities that require relocation of teeth by functional and mechanical tools to provide an ideal occlusion and a beautiful face for patients [16].

Objectives of orthodontics

The treatment provided not only satisfies the patient’s aesthetic needs but must also meet certain physiological and functional needs, including:

1. Functional efficiency

2. Structural balance

3. Harmony and beauty [16]

Assessing the need for orthodontic treatment

Because orthodontic treatments directly change the appearance of the patient’s face [17], orthodontists must be aware of the underlying issues of social psychology and the theory of facial attractiveness [18]. A person who has higher personal satisfaction than her face also has higher self-confidence [19]. In addition to these reasons, the general appearance of the teeth and face also affects the mental image of the person’s body, and in turn, the mental image of the body affects personal satisfaction with the face [20].

According to Hassebrauck [17], smile is the second most visible and pink indicator after the eyes that people want to see when evaluating the attractiveness of others. Besides, a person’s facial appearance and degree of attractiveness can have a significant impact on various aspects of personality, job, and social life. In this regard, to achieve a successful treatment plan, special attention should be paid to the differences between the views of community members and specialists. Orthodontists and surgeons should consider the patient’s attitude towards their face and the need for treatment from the patient’s point of view in presenting the treatment plan from the beginning [21]. In addition to objective reasons, subjective reasons should also be considered in treatment planning. This factor causes the difference between the need for treatment and the demand for treatment [22].

One of the most important epidemiological indicators in the field of examining the need for orthodontic treatment is the dental beauty index. This index is based on the norms of beauty defined in the society and in a way, with physical measurements and occlusal properties related to malocclusion, it connects to the aesthetic observations of dental beauty to reach a final number [23, 24].

Choosing an appropriate treatment plan for these patients should not only be based on the orthodontist’s evaluations and final results based on the beauty, function, and stability of the treatment, but also the patient’s attitude towards the order and appearance of the teeth and the patient’s mental need for treatment design. The effect of attractive teeth and face has been proven on a person’s mental state. According to the research, the motivating factor of orthodontic and surgical treatments is strongly related to the patient’s perception of how far his pink tooth appearance is different from the socio-cultural norms [25].

Malocclusion is considered one of the most important dental-maxillofacial abnormalities which, in addition to the possible adverse effects on nutrition due to its effect on the appearance and face, has a negative psychological effect on a person’s mood and makes a person prone to swelling. It causes periodontal disease and tooth decay [26]. Early detection of malocclusion and encouraging people to appropriate treatment can prevent many complications, such as oral diseases, functional disorders of the jaw, and psychosocial problems. Potential orthodontic problems include malocclusions due to the presence of impacted teeth, premature loss of deciduous and permanent molars, mild to moderate crowding, and some jaw growth abnormalities that should be diagnosed by a dentist. And if the dentist is not able to diagnose in time or initiate treatment, there is a possibility of more complex problems in the future [27].

Orthodontic treatment

Orthodontics is a branch of dentistry that deals with the development, guidance, correction, and maintenance of the face-tooth complex. This branch includes the diagnosis, prevention, prevention, and treatment of malocclusion and changes in the supporting structures. There are two clear justifications for orthodontic treatment: beauty and function. In general, the following are 4 main reasons for orthodontic treatment:

1. Improve the appearance of teeth and face

2. Improve the health of teeth and gums

3. Eliminate chewing problems means eating easier

4. Overcoming speech problems related to malocclusion

Therefore, orthodontic treatment not only regulates the position of the teeth but also improves the life of patients by improving the function of the teeth and jaw on the one hand and the beauty of the jaw and face on the other hand [28]. To achieve occlusion of teeth, there are various methods and movements of teeth in orthodontic treatment. These dental movements include tipping, appraising, and trekking, bodily movement, and rotation.

Types of orthodontics

In general, orthodontic treatments are divided into two main types of fixed orthodontics and removable orthodontics depending on the type of device used by the orthodontist.

Fixed orthodontics

Fixed orthodontics is one of the most effective methods in the treatment of oral disorders. In this method, the brackets are glued to the surface of the teeth using special orthodontic composites, and then, using wire, a strong connection is established between these brackets. In this method, the patient is obliged to keep orthodontic appliances in her mouth until the end of the treatment period, and during this period, he or she will not be able to remove it from his or her mouth [29]. In fixed orthodontics, many orthodontic disorders can be treated at specific intervals using the expertise and supervision of an orthodontist. This method is often used to move teeth and their roots in patients whose dental conditions are a little more complicated [30]. In this orthodontic procedure, oral hygiene will be very important; because if neglected, the beauty and health of the teeth will be severely endangered [31].

Removable orthodontics

Removable orthodontics is another treatment method in orthodontics. This method, like fixed orthodontics, is associated with good results. In removable orthodontics, a mold is prepared from the patient's upper and lower jaws, and then a plaque is provided for the teeth, which the patient must place in his or her mouth for a certain period.

One of the main advantages of removable orthodontics is the possibility of removing plaque from the mouth at any time. In this way, the patient can remove the plaque from his or her mouth if he or she feels discomfort while eating or drinking, and put it back in his or her mouth after eating and rinsing his or her mouth. Although dental hygiene is also important in this procedure, the work will be a little easier compared to fixed orthodontics. Therefore, the risk of dental problems in removable orthodontics will be reduced compared to fixed orthodontics. Removable orthodontics will not be as effective as fixed orthodontics in treating severe dental crowding, still, this method can treat jaw bone abnormalities.

Treatment steps

Orthodontic treatment can be divided into three stages: initial, intermediate, and final stages and treatment. Each stage of treatment imposes different needs on the archwire [32].

Initial stage

At the beginning of the treatment, the tooth displacement will have its maximum value. To optimize the biological environment for tooth movement and reduce patient discomfort, minimum stiffness and maximum range are essential needs [33]. This enables the archwire to apply a force of appropriate size at relatively large distances.

Intermediate stage

At this stage, wires with more stiffness that can have more control over the position of the tooth, replace the very flexible wires used in the first stage. The wires must be strong enough to enable the Asian teeth to withstand unwanted movements.

Final stage

Once the main displacement of the teeth has been achieved in the middle stage, the final details of their position need to be completed and then stabilized. Although round wires are used in the early stages, rectangular archwires are needed in the final stages of treatment because the tight rectangular groove allows for more precise 3D control. At this stage, the archwire must have high stiffness and low range [32]. Accordingly, the treatment phase affects both the physical and mechanical needs of an orthodontic wire.

Orthodontic wires

When the gluing and attaching is complete, an orthodontic wire is inserted into the groove of the brackets and secured in place using ligature and elastic wires. The orthodontic wire stabilizes the position of each tooth due to the mechanical interaction it makes with the bracket groove and determines the overall shape of the dental arch [34].

There are currently four metal archwires used in orthodontic treatment: stainless steel alloy, cobalt-chromium alloy, nickel-titanium alloy, and beta-titanium alloy. The use of different archwires depends on their function and the orthodontist's treatment plan. Major issues such as fast or slow, continuous or cross-sectional movements, and light or heavy forces are considered [32, 35, 36].

In the light of current knowledge and based on an interpretation of bone biology research, continuous or cross-sectional light forces are the best options for optimal orthodontic movements. This conclusion is based on an important fact:

1. Light forces minimize tissue loss, thus preventing tooth decay and subsequent movement.

2. Continuous forces create a fixed system for continuous impact. Periods of rest are needed to repair the tissues, and in this regard, it is preferable to apply forces cross-sectional [37].

Orthodontic wires were designed by mechanical interaction with bracket grooves to move teeth from the malocclusion position to the desired dental occlusion. To move the teeth, it is necessary to apply orthodontic force with a pressure higher than the capillary blood pressure of the root layer of the tooth, which is about 15 g/cm^2 and less than 20 g/cm^2 [38]. The magnitude of the required orthodontic force is usually within the range of 0.5 to 3 N. This relatively low force must be applied continuously to correct the teeth. These forces reduce the possibility of patient discomfort, tissue destruction, and latent analysis [39]. Therefore, an ideal wire should be elastic and able to create continuous and gentle force overtime. The presence of orthodontic wires is different due to the difference in the way dentists work and depends on the patient's treatment stage, the path of tooth movement, and the type of tooth movement [32].

Clinical features

Optimal features of an archwire for optimal performance are spring return, ductility, modulus of elasticity, biocompatibility, and low friction [40]. Also, the duration of use and the desired mechanical properties of the wires vary with the treatment steps (initial, intermediate, and final). However, it should be noted that there is currently no orthodontic cord that can be used alone in all stages of treatment.

Spring return

The return of spring also referred to as the activation range or operating range, is the amount at which a wire can bend without causing permanent deformation [41]. Spring return values provide the ability to apply larger actuators, which in turn will increase the working time of the device. This indicates less need to replace or adjust the archwire [42].

Stiffness

Stiffness is the amount of force applied by an appellant and is proportional to the elastic modulus. Less stiffness results in using less force. Creating a biocompatibility force includes corrosion resistance and tissue tolerance to the elements in the wire. Based on these criteria, the requirements for biocompatible dental materials are as follows:

- They should not be harmful to soft and fleshy tissues,
- More consistent in the period of deactivation of the appliance;
- More ease and accuracy in applying the given forces [43].

Biocompatibility

- They should not contain toxic permeable substances that can be released and absorbed into the circulatory system and cause a general toxic reaction in the body.
- They must be free of potential allergens that cause allergic reactions.
- They should not have potential carcinogens [44].
- They also ensure their stability in the oral environment, maintaining the desired properties over a long period.

In addition to being biocompatible, orthodontic wires must have poor bio-hosting properties. An ideal wire should not be actively growing microorganisms that create unpleasant odors and color changes and distort beauty, destroy materials or make materials that interfere with mechanical properties [34, 39].

Friction

Continuous archwire techniques involve a relative movement of the bracket to the archwire [45]. Excessive wire-bracket friction may result in loss of support or connection, resulting in poor displacement or misalignment of the tooth. A good wire is one that produces the least amount of friction at the joint surface of the bracket-wire [46].

Other influential parameters:

Factors such as the internal distance of the bracket, the curvature of the wire, to activate the wire relative to the bent arch form, the width of the bracket, and the dimensions of the bracket groove relative to the wire size, mainly affect the flexural stiffness of the archwires [47, 48]. The treatment phase also determines the choice of archwire used.

Toxic effects of metals in wires

The history of orthodontics shows that the use of metal alloys is an integral part of orthodontic treatment [49]. The use of different compounds of metal alloys for a long time in orthodontic patients has led to special attention to their compatibility biology [50]. Direct contact of metals with edible tissues and their corrosion leads to the formation of an environment that causes corrosion of metals and alloys [51]. Saliva acts as an electrolyte to conduct electrons and ions, and fluctuations in pH and temperature, enzymatic activities, microbial, and various chemicals entering the oral cavity through food and drink all contribute to corrosion [51]. As a result of this process, metal ions (often nickel, chromium, cobalt, and iron) are released into the human body, and oral mucosal cells are the first tissue in which a local corrosion effect occurs [52].

The emission of metal ions from dental alloys is caused by local and systematic chemical, mutagenic, immunogenic, and toxic effects [49]. Alloy corrosion is essential in terms of the release of elements from the alloy and the creation of biological side effects such as toxicity, allergies, mutations, and carcinogenesis, and as a result, the released ions affect the surrounding tissue [50]. Corrosion can cause the surface to rough, weaken the device, and release elements from metal or alloy. This ion release can cause discoloration of nearby soft tissue and allergic reactions in sensitive patients.

Corrosion can severely limit the ultimate strength of materials. Besides, corrosion increases the frictional force between the bracket and the archwire due to the increase in surface roughness [53]. Besides, some in vivo studies have reported biological toxicity in orthodontic patients [50]. Epidemiological data show that about 20% of people are allergic to nickel [54].

Conclusions

Today, most orthodontic brackets, braces, and archwires are made of stainless steel and nickel-titanium. These alloys contain varying amounts of nickel, chromium, and cobalt ions [55]. The most common type of metal bracket is made of stainless steel, which contains 18% chromium and 8% nickel [55, 56]. Among the most important elements released in specific biological conditions of the oral environment is nickel, which is a strong stimulant of the immune system and in some cases can cause hypersensitivity, dermatitis, asthma, and cytotoxic conditions, and DNA damage [57]. Although orthodontic alloys contain antigenic substances, they are prone to corrosion in the dynamic oral environment [55].

Normal levels of nickel (Ni), chromium (Cr), and cobalt (Co) ions in blood serum are less than 2, 0.2-0.1, and 0.3 - 0.1 ppm, respectively. And these concentrations in the urine are 0.2-2 and 0.5-2 ppm, respectively, and increasing the amount of ions released from this amount, causes a cytotoxic state for the body [58]. So far, several studies aimed at proving the biocompatibility of orthodontic alloys in vivo, to measure the content of nickel and chromium in saliva [59, 60], blood [61], urine [62], and oral mucosal cells [59, 63] in patients orthodontics. Some studies that compared the saliva of orthodontic patients without orthodontic treatment did not show significant differences in nickel and chromium levels [64]. On the other hand, the release of these ions shows significant changes depending on the sampling time and its relationship with orthodontic treatment [65]. The susceptibility of orthodontic alloys to corrosion is largely dependent on the physical and chemical properties of saliva [66].

Research shows that toxic effects occur when the body's tissues are exposed to sufficient amounts of metal ions for long periods [58]. Research has evaluated the degree of corrosion resistance of orthodontic appliances made of nickel-titanium alloys. The results of electron microscopic scans on orthodontic wires show corrosion and the release of some nickel and chromium ions [16]. Other studies have also examined the toxic and destructive effects of metal ions released from orthodontic alloys when exposed to long-term gingival fibroblasts and PDLs [57].

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article.

Funding

The study was supported by Mazandaran University of Medical Sciences.

Authors' contributions

Conceptualization: Farhad Sobouti and Sepideh Dadgar; Methodology: Mohammad Shokrzadeh and Jaber Mousavi; Writing original draft, review, and editing: Mahdi Babaei Hatkehlouei; Supervision: Farhad Sobouti; Investigation: All Authors.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors would like to express their thanks to Vice Chancellor for Research and Technology of Mazandaran University of Medical Sciences for supporting this research.

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