AESTHETIC ORTHODONTIC ARCHWIRES: THE STATE OF ART

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SUMMARY
Despite the improved aesthetics of this type of archwires, there are differing opinions in the literature about their actual clinical validity because of the problems that may arise during their use in the oral cavity. A systematic review was performed to analyzed studies published over the last 25 years about aesthetic orthodontic archwires, in order to: analyze the technical characteristics and biotechnological properties, highlight the reliability and long-term effectiveness, and establish which are the most significant physical variables in determining the clinical efficacy during the orthodontic treatment and hypothesize future developments. A total sample of 24 articles was selected. Although initially the outer coating improves the aesthetic value of the orthodontic archwire, the wear that characterizes clinical use creates significant changes in surface, mechanical properties, such as sliding and friction, impacting negatively on the biocompatibility and aesthetics.
Thermoplastic polymers could represent an excellent alternative and a good future prospect for the production of orthodontic wires characterize by an high aesthetic value and optimum mechanical properties.

Key words: coated archwires, aesthetic archwires.

Introduction

In the last decade, the number of adult patients willing to face orthodontic treatment is increasing rapidly and, consequently, also the demand for orthodontic devices with high aesthetic value. It was therefore necessary to develop innovative materials that meet the expectation of adequate clinical performance, taking into account the aesthetic parameters of the patient (1).
To meet these demands, the industries have produced materials with low visual impact, such as aesthetic orthodontic brackets and aesthetic conventional ligatures (ring shape) in latex or polyurethane and unconventional aesthetic ligatures (Slide low Friction - Leone® Spa) in polyurethane (2-4).
In particular, as regards the construction of aesthetic orthodontic brackets, it has involved a wide range of materials, such as polycarbonates, ceramics (polycristalline and single crystal aluminum oxide) and bioceramic (zirconium bioxide) (5).
The first aesthetic orthodontic archwire produced without metallic material, contained a core of silica, an intermediate layer of silicone resin and an outer layer of nylon (Optiflex Ormco) (6, 7).
Subsequently Fallis and Kusy devised a new aesthetic orthodontic archwire containing glass fibers (Owens Corning, Toledo, Ohio) embedded in a polymeric matrix composed of bisfenoloA-diglycidylether methacrylate and triethylene glicodimetacrilato (8).
Imai et al. devised an arch reinforced polymer fibers consisting of polymethylmethacrylate (PMMA) and CaO-$P_{(2)}O_{(5)}$-$SiO_{(2)}$-$Al_{(2)}O_{(3)}$ (CPSA) with the aim of further improving the aesthetic appearance, but also to make the mechanical properties

more similar to those of metal archwires (9).
Despite the excellent aesthetic characteristics of the latter, to date the coated metallic archwires are the only aesthetic orthodontic wires available for clinical use due to their own physical abilities of wear resistance and biocompatibility (10, 11). Of these, the most used in orthodontics are constituted by a core of NiTi alloy, coated with plastic resin materials (such as synthetic resin or fluorine-containing epoxy resin mainly composed of polytetrafluoroethylyene or Teflon®) and hydrogenated carbon or zirconium dioxide resins (12, 13).
However, the best results are obtained with Teflon® coating NiTi archwires, which produces less friction than the corresponding uncoated (14).
Subsequently, were introduced other types of coating such as aluminum nitride and titanium (TiAlN), tungsten carbide/carbon (WC/C) and diamond-like carbon in order to protect the alloy from the corrosive effects of mouthwashes and toothpastes fluoride gel-based commonly recommended to orthodontic patient in the practice of oral care at home (15-17). Such of these coatings have limited corrosion phenomena and an average reduction of nickel ions released in the oral cavity of about 85% (11, 16, 17).
Have recently been introduced two types of NiTi aesthetic archwires, the Woowa (Dany Harvest, Seoul, South Korea) and the Bioforce High aestethic (Dentsply GAC, Islandia, NY), whose surface coatings show enhanced properties for both aesthetic impact, which for the physical-mechanical characteristics, with a significant reduction of surface roughness compared to the untreated archwires, and a substantial increase in smoothness during the orthodontic movement, thereby ensuring a better biocompatibility of the final product (18).
The aim of this study was to perform a systematic review of the literature analyzing all the scientific articles published in recent years about aesthetic orthodontic archwires, in order to: analyze the technical characteristics and biotechnological properties, highlight the reliability and long-term effectiveness, and establish which are the most significant physical variables in determining the clinical efficacy during the orthodontic treatment and hypothesize future developments.

Materials and methods

To perform a systematic review of the literature were chosen initially some basic parameters, inclusion and exclusion criteria, which each article would have to meet in order to be considered appropriate to the purposes of this research.
It was conducted in MEDLINE and PUBMED database by choosing the following keywords: “coated archwires” and “aesthetic archwires” within the limits of research all inclusion and exclusion criteria described below.
Were analyzed studies published over the last 25 years, assuming a total sample of 24 articles.
The selected languages are English and Italian in order to ensure a clear understanding of the text.
Were evaluated scientific articles and reviews on experimental work carried out *in vivo* and *in vitro*. This decision was taken in line with the objectives of this research, aimed to the study and understanding of the clinical efficacy of long-term orthodontic arches.
According to further inclusion and exclusion criteria chosen, were eliminated all the articles written in languages other than Italian and English, published before 1990, making use of experimental tests on animals.
According to these criteria were available for an initial analysis of 44 articles.
Of these, 11 were discarded because not congruent to title to the objectives and parameters established in the present research.
Subsequently other 9 of them were discarded by abstract because no respectful inclusion criteria chosen.
The remaining 24 articles were analyzed and divided into 3 groups.
The data collected were used to extrapolate general information on the use and effectiveness of aesthetic orthodontic archwires during orthodontic treatment. The purpose of this final analysis was to examine specific clinical parameters of aesthetic orthodontic archwires: the aesthetic factor and the clinical performance of the coating materials, the effectiveness of these materials on the basis of parameters such as mechanical properties of the load and deflection, corrosion resistance, and sliding

properties, and the reliability of the techniques of application of the materials themselves.

Results

The sample of articles has been divided into 3 groups according to the characteristics and the properties of each type of orthodontic archwires:
in Group 1 (G_1) are included articles that examine the mechanical properties of load and deflection by means of certain tools such as the three-point bending test (6, 18, 19, 26-29);
in Group 2 (G_2) articles that evaluate the corrosion resistance (17, 30-32, 34-36);
while in Group 3 (G_3) than those who analyze the properties of the mechanical sliding (10, 13, 14, 40-42, 45), surface roughness and adhesion of the coating (18, 31, 32, 46-48).
Every aspect was analyzed individually and were assessed both changes that the veneering brings to the properties of conventional orthodontic archwires, both the modifications that the coatings themselves undergo as a result of their stay in the oral cavity by physical-chemical stress.
This is to assess the actual clinical efficacy and long-term therapeutic of such archwires.

Discussion

G1: Mechanical properties of load and deflection (3-point bending test)

The performance of an orthodontic arch depends on the material of which it is composed and the geometry of its cross-section.
The application process of coating includes a surface treatment of the wire and the use of Cathodic arc physical vapor deposition (PVD) or compressed air as a means of transport for the resin particles (polytetrafluoroethylene) sprayed to cover the archwire. The set wire-coating is then further heat-treated in a microwave chamber (12, 13, 18).
The mechanical properties of the metal arches may be affected during this process and may be necessary any changes about the size of the inner core of the alloy to compensate for the thickness of the coating layer (19).
It's important to consider that, aesthetic archwires may have a metal core inside smaller sizes to compensate for the thickness of the coating layer. To achieve the same nominal size, the coated archwire is constructed from a smaller archwire that, when coated, reaches the nominal dimensions stated for the archwire (6).
Industries actually indicate as usual cross-sectional dimension of the aesthetic archwire, not the real size of the wire, but a value including the thickness of the set archwire-coating. Therefore, considering that the size of the metal wire is a substantial component of the resultant of the forces, certain variations of its section could affect the mechanical properties of the archwire in terms of torsion and rigidity and about its final clinical performance (20, 21).
These mechanical properties can be examined using a 3-point bending test. The advantage of a 3-point bending test is to be able to get a mechanical simulation very similar to clinical application comparing different orthodontic wires with superelastic properties (22, 23). Through this test it's possible to analyze several parameters: the load curve, is the force required to engage the wire in the brackets; the discharge curve, which represents the force transferred to the teeth during the orthodontic treatment (24); the modulus of elasticity, which corresponds to the archwire stiffness or rigidity of the material (higher values indicate more rigid wires); the form of resiliency, or the ability of a material to store energy when it is deformed (25).
Starting from these considerations and using the 3-point bending test several study evaluates the properties of load-deflection of the aesthetic archwires, providing information on the behavior of the wires when undergoing deformation and comparing them with conventional orthodontic archwires.
Da Silva et al. have analyzed 3 groups of coated archwires: coated orthodontic wires with a cross-

sectional dimension identical to that of uncoated wires control group, archwires with all the surfaces completely coated, wires of which had been coated only the vestibular surface. The values about the mechanical properties of the archwires after a period of clinical use of 21 days, was compared with those of the corresponding unused orthodontic wires of the control group. These wires, both new and used, thus producing lower forces of loading and unloading, possess a greater modulus of elasticity, a lower modulus of resilience and they also demonstrate a minimum values of bending compared to the corresponding archwires of the control group (19).
A similar investigation into the mechanical and aesthetic properties of new generation coated nickel-titanium wires in the as-received state and after clinical use was conduced by Bradley et al. Sixty one subjects were randomly assigned to four groups, two groups of coated wires and two groups of comparable, non-coated controls. The period in the mouth ranged from 4 to 12 weeks after insertion. Three-point bending tests were done on as-received and used wires and its results indicate a wide variation in test results with large standard deviations among all the groups (26).
Elayyan et al. performed a randomized clinical trial about NiTi wires coated with epoxy resin. Run the 3-points bending test reported that the coated wire used has values of force loading and unloading lower than those typical of a new wire (27).
In a second study conducted in 2010 by Elayyann et al., four types of orthodontic archwires were investigated, 2 superelastic nickel-titanium and 2 coated Ultra-aesthetic archwires in 0.016-in and 0.018 x 0.025-in dimensions. All specimens were tested in a universal testing machine in a 3-point bending test. Coated superelastic wires produced statistically significantly lower forces in loading and unloading when compared with the superelastic nickel-titanium wires at most archwire deflections ($P < 0.01$). For all wires, an increase in size resulted in an increase in force (6).
Alavi in 2012 compares the load-deflection and surface properties of 3 types of archwires including ultra-aesthetic polycoated, ultra-aesthetic epoxyresin coated and conventional (uncoated) superelastic nickel-titanium (NiTi) archwires in conventional and metal-insert ceramic brackets. Them were tested in three-bracket bending test machine. It results epoxyresin-coated archwire had the lowest force and highest end load deflection point (ELDP) (28).
In orthodontics, have been recently introduced 2 new aesthetic NiTi wires, their trade names are: Woowa (Dany Harvest, Seoul, South Korea) and BioForce High Aesthetic (Dentsply GAC, Islandia, NY). Woowa has a structure of double-layer coating: the inner one is made of silver and platinum, instead the outer layer consist of highly aesthetic polymeric coating. Bioforce High Aesthetic is made of a coating in rhodium with a low reflectivity for the white color. About them, 3-points bending tests were carried out in order to: study the mechanical properties of these archwires, which were then compared with those of the not covered wires. The results showed that, in both cases, the coating adversely affects the mechanical behavior of the archwires (18, 19).
Therefore the reduction of the internal dimensions of the metallic core seems to be actually the variable most responsible for changes in the mechanical properties of the coated orthodontic wires (19). This is the reason why the latest development in aesthetic orthodontic appliances is a polymeric orthodontic archwire without metal inner core, with high springback and hight ductility. In a study performed in 2014 Varela et al. showed that mechanical strength of a new thermoplastic polymer archwire was lower than metallic alloys but is adequate for the first stage in orthodontic therapy (29).

G2: Corrosion resistance

In 1999 Kim analyzed significant differences in corrosion phenomena of stainless steel, nickel titanium, nitride and epoxy-coated nickel titanium and titanium orthodontic wires with the result that epoxy-coated nickel titanium wires exhibited the least corrosive potential (30).
Da Silva et al. have examined 4 types of aesthetic rectangular wires to evaluate the thickness, surface characteristics and stability of the outer coat-

ing before and after 21 days of exposure in the oral cavity, compared them with those belonged to uncoated stainless steel and NiTi archwires. The results of this search demonstrated that the aesthetic wires does not show a uniform thickness of the coating. These wires therefore have a lower aesthetic value in that they have a non-durable coating after exposure in the oral cavity. The remaining coating has also produced a greater surface roughness of the archwires examined than those in the control group (31, 32).
Cai et al. led a study on the corrosion resistance and fracture toughness of different types of archewires coated in comparison to traditional wires and scored three categories of arch: wire without modification, wire with crystallographic modifications and wire with Teflon coating outdistanced (33).
It's clear therefore that, the aesthetic coating preserves the orthodontic wire metal core by the corrosion processes, or by fluoride-induced corrosion and improve orthodontic friction (17, 34, 35) but the type and nature of coating material can effectively influence the anticorrosive features of NiTi wires, compared with its surface roughness values (36) and after a prolonged use in the oral cavity anyway, are themselves subject to corrosion processes. It depends on the action of the oral fluid, the nature of the material used for the cladding and the presence of imperfections due to an incorrect procedure of affixing the material itself (12).
The corrosion of the archwire coating after clinical use in the oral cavity can also lead to undesirable results such as tartar buildup, microstructural and chemicals changes that cause a mechanical deformation of the arch and the release of chemical elements within the oral fluids (14).

G3: Properties of the mechanical sliding, surface roughness and adhesion of the coating

Therefore, the corrosion phenomena of the coating have negative impacts on biocompatibility, aesthetics and also adversely affecting the physical and mechanical properties such as the sliding ability of the wire (34).
The increase in friction due to the surface roughness is widely discussed in the literature (37-39). Recent studies have revealed a lower resistance to sliding of the orthodontic wires coated than uncoated (10, 13, 40, 41).
There are many different methods and materials used to improve the surface of the wire (16, 42-44). Farronato et al. in 2012 have made a study *in vitro* comparing some of those, and found that all coatings improve the sliding characteristics compared to those non-coated, but that the best results are obtained with the Teflon coating (14).
However, studies performed *in vivo* have shown that the clinical use of orthodontic wires coated increases their surface roughness and the level of friction (18, 28, 45-47).
Beside intra-oral exposure and archwire-bracket friction of coated wire altered the morphology and changed the elemental composition of the surface due to the process of corrosion, adhesion of organic matters and ionic exchange with oral fluids (48).
With the intention to overcome all these problems, the latest technological development in orthodontic research are projected into a solution regarding high aesthetic value that maintained contextually a satisfactory clinical efficacy. It has led to the production of a translucent polymer archwire with a considerable elastic return and a high ductility (49).
Marroco and Goldberg have developed a wire made of a new polymer based on polyphenylene, whose extremely rigid molecular structure bears a high load force in addition to possessing a high modulus of elasticity (50, 51).
The clinical trial has demonstrated the effectiveness of tooth movement with such wire during the first stage of orthodontic treatment (leveling and alignment) (52). Recently, Hadjichristidis et al. examined some copolymers: multigraft and polystyrene-polyisoprene-g, thermoplastic elastomers with high tensile strength and rupture (percentage increase of about 1550%) (53, 54).
The mechanical properties of these copolymers are guaranteed by the architecture and morpholo-

gy of both molecules in fact, these polymers have a very similar behavior to superelastic materials. From this it derives an aesthetic archwire that has therefore excellent mechanical properties and good plasticity, parameters which allow to perform a similar curvature to that of stainless steel orthodontic wires. Furthermore, the coefficient of friction is lower than that of uncoated metal ones (55, 56).

Finally, an interesting study in 2014 conducted by Valera et al. introduces a new thermoplastic polymer for orthodontic applications, obtained and extruded into wires with round and rectangular cross sections. Tensile, 3- point bending test, friction and stress relaxation behaviour, and formability characteristics were assessed. The results have demonstrated that stresses delivered were generally slightly lower than typical beta-titanium and nickel-titanium archwires. The polymer wire has good instantaneous mechanical properties; tensile stress decayed about 2% over 2 hours depending on the initial stress relaxation for up to 120 hours. High formability allowed shape bending similar to that associated with stainless steel wires. The friction coefficients were lower than the metallic conventional archwires improving the slipping with the brackets (57). In conclusion, according the Authors this new polymer could be a good candidate for aesthetic orthodontic archwires (29, 58).

Conclusions

In conclusion, despite the improved aesthetics of this type of archwires, there are differing opinions in the literature about their actual clinical validity because of the problems that may arise during their use in the oral cavity.

Although initially the outer coating improves the aesthetic value of the orthodontic archwire, the wear that characterizes clinical use creates significant changes in surface, mechanical properties, such as sliding and friction, impacting negatively on the biocompatibility and aesthetics (47, 58).

Thermoplastic polymers could represent an excellent alternative and a good future prospect for the production of orthodontic wires characterize by an high aesthetic value and optimum mechanical properties (29, 49-55).

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