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Qualitative and Quantitative Evaluation of Different Types of Orthodontic Brackets and Archwires by Optical Microscopy and X-ray Fluorescence Spectroscopy

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Abstract: The wear behaviour and chemical composition of orthodontic components influence the mechanical characteristics of a fixed orthodontic treatment. The purpose of this paper is to evaluate the surface alterations of different types of brackets (aesthetic, metallic, and conventional self-ligating) and archwires (superelastic and thermal) subjected to wear tests through optical microscopy and, subsequently, to identify the chemical elements of accessories by X-ray fluorescence. The cycles (5000 for each bracket and 10,000 for each wire) of the tribological test were carried out in dry conditions inside a machine that allows alternating sliding. The results of the study highlighted different wear behaviours even within the same type of brackets and archwires. The monocrystalline sapphire brackets maintain their aesthetic properties despite traces of wear inside the slots and contain minimal amounts of nickel. Superelastic NiTi archwires have a better overall rating than thermal wires, as they do not show significant surface wear alterations.

Keywords: wear; nickel; bracket; archwires; NiTi



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1. Introduction

Friction is the resistance to movement during sliding when an object moves tangentially against another; wear occurs whenever a surface is exposed to another surface, resulting in a removal of material through mechanical action [1]. In dentistry, wear processes of materials, such as abrasion and corrosion, cause deterioration of materials and release of elements into the oral environment [2]. Wear resistance of dental materials is important for clinical longevity, aesthetics, and resistance of dental plaque [3,4]. The choice of metal materials has been a long concern of biomaterial science, because it is mainly influenced by corrosion. Furthermore, these materials can hardly be tolerated in the oral cavity due to the poor biocompatibility of their corrosion products [5]. In particular, friction between traditional brackets and archwires can cause various problems, such as release of toxic chemical elements, periodontal lesions, and dental root resorptions [6].

Understanding frictional forces is essential for orthodontists, because the sliding resistance at the wire–bracket interface influences tooth movement, reducing the efficiency of orthodontic treatment [7]. The factors that affect the frictional resistance include the dimensions and materials of the bracket and wire, surface roughness of the components, angulation of the wire with respect to the bracket, type of ligation, saliva, and biological functions [8–11].

Currently, the combination of stainless steel (SS) brackets and SS wires are preferred for their low frictional force values [12]. Nickel–titanium (NiTi) archwires are mainly used during the first phase of fixed orthodontic treatment for their higher springback properties, biocompatibility, shape memory effect, and superelasticity [13]. The use of heat-activated NiTi archwires resulted in favourable shape memory properties, low stiffness, high springback, and superelasticity, compared to previous generation NiTi wires [14]. Adding copper

(Cu) to the NiTi wire structure (Cu–NiTi) increases the transition temperature range, reduces loading stress, and at the same, time results in high unloading stress, leading to more effective orthodontic movement [15,16]. Understanding the tribological and corrosion properties of NiTi alloys is necessary for the clinician in choosing the appropriate orthodontic treatment. Indeed, NiTi wires are unstable during long-term use due to the erosive effect of saliva, causing the release of nickel and elements into the oral cavity [17].

Brackets of various materials and designs have different frictional properties. SS brackets are the most used in orthodontics, because they show a low resistance to sliding [18–20]. In the field of aesthetic materials, ceramic brackets have been introduced, but they fracture more easily and have high frictional resistance [12,19,21,22]. The difference was found in the surface roughness of the materials, as SS brackets have smooth surfaces compared to aesthetic brackets. To overcome the problem of aesthetic brackets' increased friction, metal or silica slots have been incorporated into the ceramic brackets in order to improve their physical properties and to reduce the sliding resistance [23].

In recent years, different designs of self-ligating brackets have been developed, which have several advantages in terms of oral hygiene, aesthetics, wearing comfort, and treatment duration [24]. The reduced friction with self-ligating brackets is one of the main advantages over conventional brackets [25,26]. The debate on the use of an active or passive ligating mechanism is still ongoing. The active clip applies force on the wire, providing greater control with the appliance, while the passive clip does not exert any active force, because the slot offers more space for the wire, resulting in less friction [27].

Surface alterations in orthodontic components might compromise the appliance aesthetics, modify torque expression, cause fractures during clinical use, and influence the friction between the bracket and the wire [28–30].

Scientific research has focused heavily on the friction behaviour of orthodontic materials. However, the alterations that certain brackets and wires undergo during orthodontic treatment are not entirely clear. Furthermore, quantifying the chemical elements released due to wear caused by friction is a fundamental requirement that must be considered when choosing the most appropriate orthodontic components to use. In the oral cavity, it is important to maintain a balanced microbiome [31], and the adoption of orthodontic treatment may have various effects on such equilibrium [32]. Corrosion effects due to the interaction of orthodontic components with the oral environment under the effect of pH and immersion time should be considered. Significant differences in the mean corrosion time were assessed on different materials [33]. The effect of wear on orthodontic components must be evaluated in order to avoid a loss of mechanical performances [34] and durability [35] with the release of chemical elements [36].

The objective of this paper is to analyse the wear behaviour of various types of brackets and archwires by means of optical micrographs for the qualitative evaluation of material removed during the tribological test. Finally, X-ray fluorescence (XRF) analysis was performed to identify the constituent chemical elements of the studied materials. The focus of our research was a simple and comparative study that can provide clinicians with useful information regarding the possibility of material release in the patient's oral cavity, in order to define a proper orthodontic treatment.

2. Materials and Methods

2.1. Brackets and Archwires

Wear tests were performed on different types of orthodontic components, i.e., aesthetic, self-ligating, and conventional brackets associated with NiTi and thermal archwires. Tables 1–5 show the manufacturer's name, the identification codes, and the number of components tested. Some of them are not reported with their commercial name.

The Radiance bracket (American Orthodontics) is made of monocrystalline sapphire with translucent properties that blend with the natural colour of the tooth. The mechanical base in transparent alumina oxide allows perfect adhesion to the buccal tooth surface. The monocrystalline structure confers a high degree of breaking strength. Zephyr (Micerium

Orthodontics) is a monocrystalline sapphire bracket with a fully titanium coated body, low profile design, and excellent performance and sliding, similar to the metal brackets. The AB1 (Manufacturer 1) is a pure monocrystalline sapphire bracket that features perfect transparency, optimized body strength, rounded edges, and a low-profile design for reducing the patient's discomfort (Table 1).

Table 1. Aesthetic brackets tested.

Company	Commercial Name	Identification Code	N° Test Performed
American Orthodontics	Radiance	Straight-Wire A002-7107R	1
Micerium Orthodontics	Zephyr	BZ2B31	4
Manufacturer 1	AB1	LR-MBT-022-41	1
		LR-MBT-022-42	1
		LR-MBT-022-43h	1
		LR-MBT-022-44h	1

Table 2. Self-ligating brackets tested.

Company	Commercial Name	Identification Code	N° Test Performed
American Orthodontics	Empower	Straight-Wire 485-3106	1
Micerium Orthodontics	Mistral Plus	BMP2B31	4
OO Dental	O-Eyes	Roth LR1	4
Manufacturer 1	SB1	LR-MBT-022-41	1
		LR-MBT-022-42	1
		LR-MBT-022-43h	1
		LR-MBT-022-44h	1

Table 3. Conventional brackets tested.

Company	Commercial Name	Identification Code	N° Test Performed
American Orthodontics	LP Low Profile	Bennett, Mclaughlin, Trevisi A393-2225 R	1
Micerium Orthodontics	Vesper Plus	BVP2B31	4
Manufacturer 1	CB1	LR-MBT-022-41	1
		LR-MBT-022-42	1
		LR-MBT-022-43h	1
		LR-MBT-022-44h	1

Table 4. Ni-Ti archwires tested.

Company	Commercial Name	Identification Code	N° Test Performed
American Orthodontics	NiTi Memory Wire Upper 0.016	A857-506W	1
Micerium Orthodontics	Spektra NT Plus	ASPNE1622U	2
Manufacturer 2	NiTi SE Upper 0.016 × 0.022	NT1622U	1

Table 5. Thermal archwires tested.

Company	Commercial Name	Identification Code	N° Test Performed
American Orthodontics	Tanzo MID w/stops Low 0.018 × 0.025	827-3L-1825PSW	1
Micerium Orthodontics	Spektra TH Plus	ASPTE14U	1
Manufacturer 2	NiTi-Cu Upper 0.014	CP14U	1

Empower (American Orthodontics) is a self-ligating bracket with an interactive/passive hybrid system that offers the benefit of less friction at the start of treatment and more control towards the end to help perfect torque and rotation. In cases of anterior teeth, the Empower's selective engagement clip allows small wires to slide with reduced friction and actively

engages larger diameter wires to increase torque and rotation control during the intermediate and final phases of the treatment. In the posterior teeth, passive clips allow for low friction and reduced force mechanics throughout the treatment; furthermore, no wires are actively engaged by the clip. Mistral Plus (Micerium Orthodontics) is an interactive/passive self-ligating bracket with integrated hooks and groove of the highest precision. It features anatomical and adherent bases, a flat nickel and titanium clip, and flexible independent tabs to reduce friction and improve rotational control. The O-EYES (OO Dental) is a passive, self-ligating bracket with an extra low-profile, 17% lower than others, that determines accurate expression, thanks to shorter distance between slot and base; thus, the arch wire is closer to resistant centre of teeth. Moreover, it has an MIM (Metal Injection Molding) base made of premium SS material to guarantee its bonding strength and durability. The SB1 (Manufacturer 1) is a passive self-ligating bracket that enables for outstanding rotation and torque control for each case and lower friction sliding during treatment. Moreover, it has a unique mesh type base with an exceptional SS body, which allows for outstanding durability while processing (Table 2).

LP Low Profile (American Orthodontics) is the versatile metal twin bracket system with a technologically advanced and visually intuitive design. The diagonal torque and diagonal angulation make bonding precision simple, delivering exceptional results with fewer wire bends. The Vesper Plus (Micerium Orthodontics) is a low-profile metal bracket, made in a single body with MIM system that guarantees precise dimensions and information and avoids the detachment of the base from the body of the bracket. In addition, its mesh provides excellent retention, comfort, and efficiency. The CB1 mini bracket (Manufacturer 1) provides all the proven clinical features of full-size brackets in a smaller size for greater comfort and improved aesthetics (Table 3).

The NiTi Memory Upper archwire (American Orthodontics) features a round section (0.016 mm), is fully active at ambient temperatures, and has superelastic properties demonstrating excellent springback. In addition, it exerts moderate force, which is crucial in the early and intermediate stages of treatment. The Spektra NT Plus wire (Micerium Orthodontics), which has a rectangular cross section of $0.016 \times 0.022 \text{ mm}^2$, is made in the "Natural Form" shape, and is resistant to deformation during handling. The Manufacturer 2 NiTi wire ($0.016 \times 0.022 \text{ mm}^2$ rectangular cross section) has an excellent finishing, which reduces sliding friction and increases patients' comfort, and has great resistance to fatigue and permanent deformation (Table 4).

Thanks to the addition of the copper alloy, Tanzo Premium Heat Activated archwire (American Orthodontics) delivers lower loading forces and more consistent unloading forces that allow controlled tooth movement for predictable results. Tanzo is resilient with excellent resistance to permanent deformation and is available in mid and low force levels. This kind of wire has a rectangular cross section of $0.018 \times 0.025 \text{ mm}^2$ with a "Natural Arch Form III" shape and mid force. The Spektra TH Plus wire (Micerium Orthodontics), with 0.014 mm^2 round cross section, is a thermal wire with a "Natural Form" shape that can be moulded at room temperature and reaches maximum moldability below $20 \text{ }^\circ\text{C}$. Once positioned in the oral cavity, at a temperature of $37 \text{ }^\circ\text{C}$, it returns to its original shape, thus stressing the teeth with light and constant forces. Heat-activated NiTi wire is soft under room temperature, reacts to the heat in the patient's mouth, and exerts continuous force as it returns to its original form. The heat-activated NiTi-Cu upper wire (Manufacturer 2) is also soft at room temperature, reacts to heat in the patient's mouth, and exerts a continuous force as it returns to its original shape (Table 5).

2.2. Test Protocol

For each bracket and archwire, two micrographs were performed with a Leica M165C microscope to evaluate the slot surfaces before and after tribological tests. Zoom magnifications of $4\times$ and $10\times$ were adopted, respectively, to observe the brackets and wires. Saliva can influence the tribological behaviour of orthodontic components. It can reduce the material wear in comparison to dry sliding [37] and, without its effect, a large amount of debris is released within the oral cavity. However, in this work, the worst tribological

conditions, where no positive effect of saliva is present between the brackets and the wires, has been evaluated. The dark colour highlighted by the micrograph indicated the presence of debris (particles of material removed during the friction phenomenon). Each component was assigned an overall score from 1 to 10, considering the combined effects of the signs of wear, the loss of transparency (in aesthetic brackets), and the release of chemical elements.

Tribological tests were performed with a machine that allows the alternate sliding of the wire inside the bracket slot. For each bracket, 5000 cycles were performed in dry conditions in the absence of lubrication, while each arch was tested for 10,000 cycles. Several brackets and arches were tested at the same time, preventing the same sections of wire from coming into contact in the slot of two different brackets. Finally, XRF analyses were performed on each component in order to evaluate its chemical composition. The SPECTRO xSORT Alloy (X-ray tube with Rh anode, up to 50 kV tube voltage) with the standard configuration setup was adopted.

2.3. Testing Machine

To carry out tests on orthodontic components, a testing machine was designed at the University of Messina. It consists of a support base made of aluminium and plexiglass, on which screws are fixed as a support for the brackets (Figure 1). The brackets were fixed on the screws thanks to an epoxy resin, and the wire was slid over them. As can be seen in Figure 1, several brackets can be tested simultaneously during the same test.

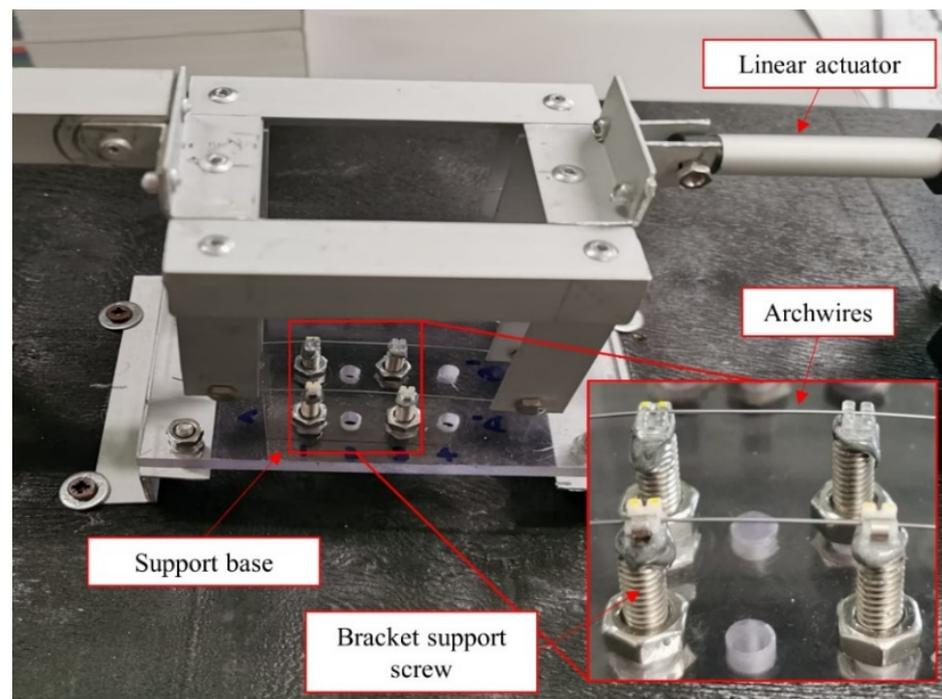


Figure 1. Details of the support base and the screws on which the brackets are fixed.

The archwires were fixed on an aluminium support frame that allows the movement of alternating translational motion, thanks to an ACTUONIX[®] feedback electric linear actuator, with a maximum force of 50 N and 100 mm stroke.

The machine control software was made in LabVIEW[®], and it was possible to check the position of the actuator, as well as to set the number of cycles to be performed and the maximum and minimum stroke values for a test. During the tribological test, the number of cycles that the actuator performs was monitored.

3. Results

The micrographs show the wear behaviour of orthodontic accessories. The scores reported in the following tables are based on the overall evaluation regarding the traces of wear and the release of chemical elements. For all tested components, the same tribological behaviour was noted; therefore, the results of a single test per type are reported.

3.1. Aesthetic Brackets

Following the tribological test, the Zephyr bracket showed minor traces of wear, maintaining excellent aesthetic properties (Figure 2). The Radiance bracket reported general wear along the contact slot, with a higher concentration of material removed along the external walls of the slot. However, there was no excessive opacification of the bracket that maintained good aesthetic properties after the test (Figure 3). The AB1 bracket reported the greatest traces of wear in the slot due to the sliding of the wires, causing the removal of material near the external areas of the slot and greater opacification of the bracket (Figure 4). The XRF results of the aesthetic brackets are reported in Table 6, while Table 7 reports the overall assessments. Most of the chemical elements have minimal values. The amount of nickel in percentage is lower in Zephyr (0.009%), although it is also not significantly present in Radiance and AB1. Aluminium is mostly represented in all aesthetic accessories, especially in the AB1 bracket (99.9%).

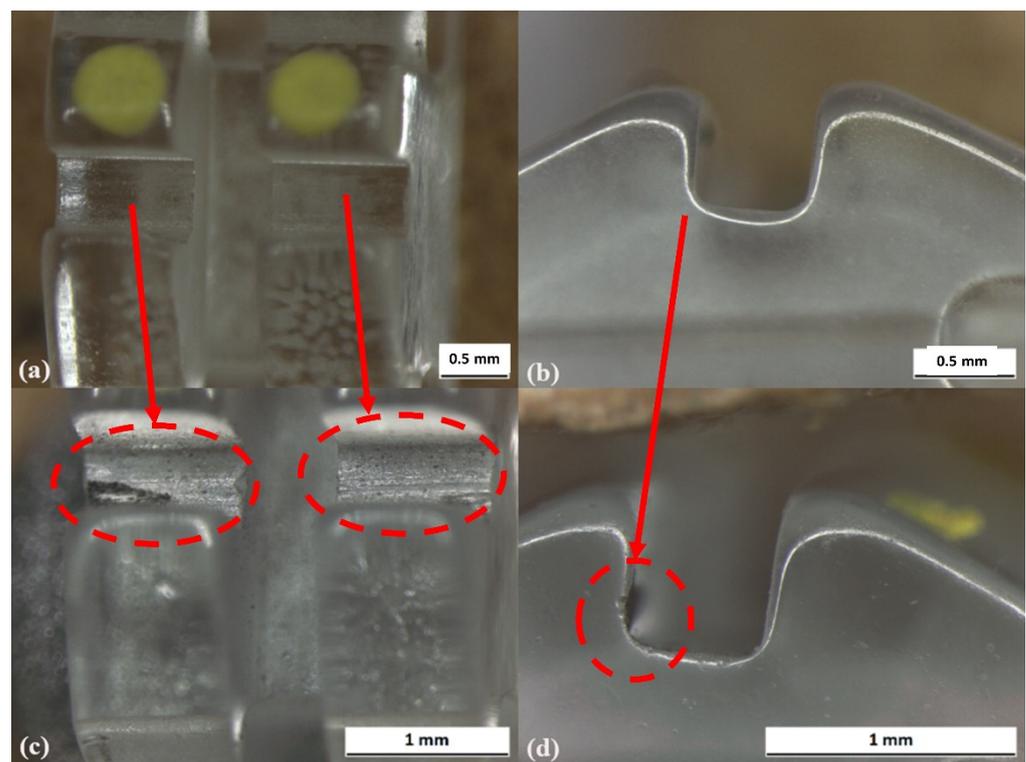


Figure 2. Zephyr bracket (Micerium Orthodontics) in top and side view: (a,b) before the test; (c,d) after the test.

3.2. Self-Ligating Brackets

The O-Eyes bracket showed a slight deterioration of the slot following the tribological test (Figure 5). The Mistral Plus bracket reported good tribological behaviour without particular traces of wear (Figure 6). The Empower bracket also exhibited perfect behaviour during wear tests (Figure 7). The SB1 bracket had damage due to wear on the whole slot, with a slight increase in the removal of material in the external areas of the slot (Figure 8).

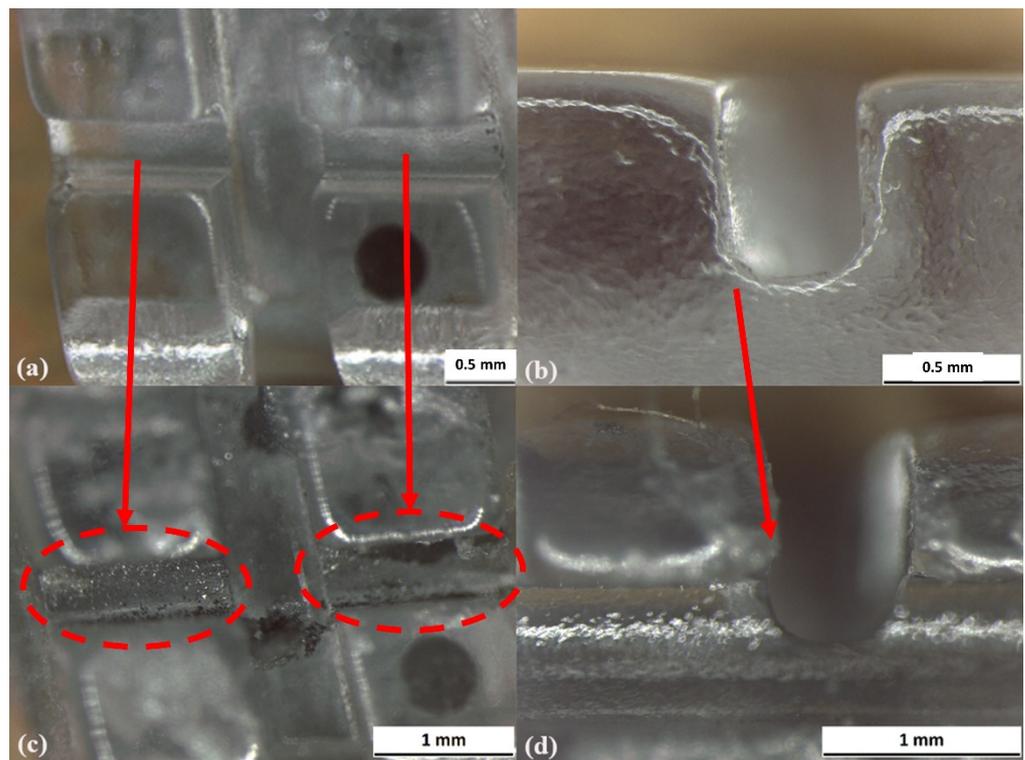


Figure 3. Radiance bracket (American Orthodontics) in top and side view: (a,b) before the test; (c,d) after the test.

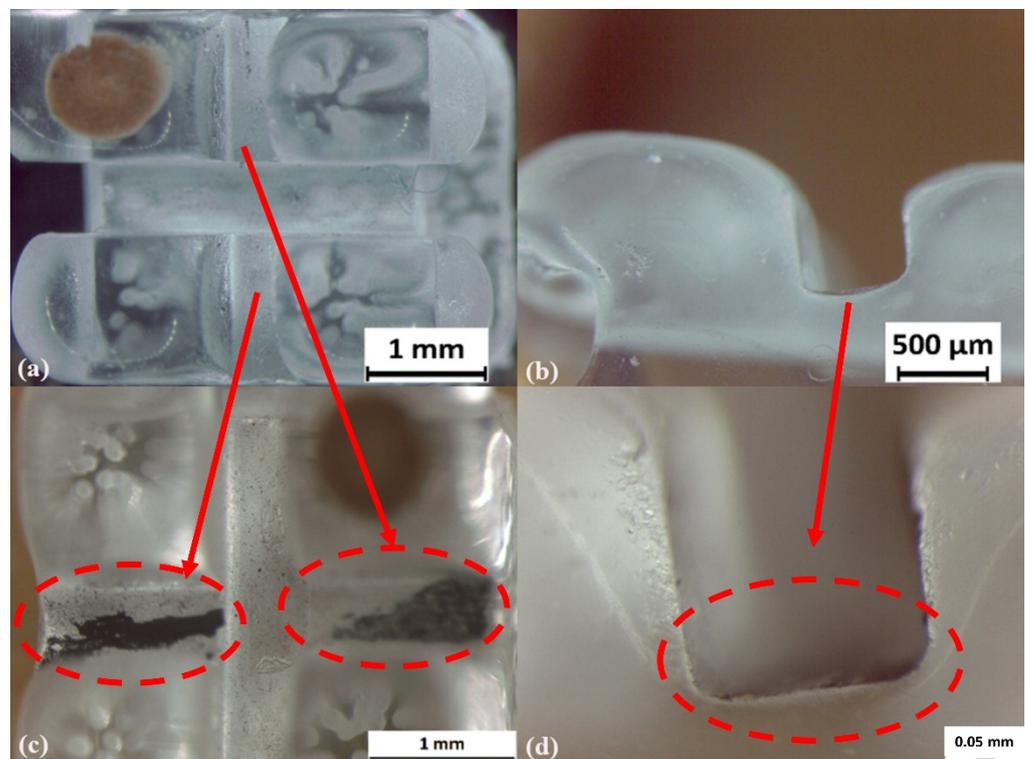


Figure 4. AB1 bracket (Manufacturer 1) in top and side view: (a,b) before the test; (c,d) after the test.

Table 6. XRF results of the aesthetic bracket. Percentage by weight.

Chemical Element	Zephyr	Radiance	AB1
Aluminium (Al)	49.3	40.6	99.9
Silver (Ag)	0.01	0.011	0.18
Cadmium (Cd)	0.014	0.016	0.024
Cobalt (Co)			
Chromium (Cr)	<0.003		<0.003
Iron (Fe)	<0.005		0.016
Phosphorus (P)			
Ittrium (Y)	0.009	0.009	0.009
Magnesium (Mg)	<99.9	57	<<0.001
Manganese (Mn)	<0.002		<0.003
Molybdenum (Mo)	0.005	0.006	0.007
Nickel (Ni)	0.009	0.035	0.076
Niobium (Nb)	0.003	0.003	0.005
Lead (Pb)	0.007	0.005	0.018
Copper (Cu)	0.003		<0.002
Silicon (Si)	0.45	1.85	0.39
Tin (Sn)			
Titanium (Ti)	0.12	0.11	>>0.18
Thorium (Th)	0.011	0.011	0.019
Tungsten (W)			
Vanadium (V)			
Zinc (Zn)	<0.002		<0.002
Zirconium (Zr)	0.006	0.04	0.007
Sulfur (S)			

Table 7. Overall rating of the aesthetic brackets.

Company	Commercial Name	Overall Rating
Micerium Orthodontics	Zephyr	9/10
American Orthodontics	Radiance	7/10
Manufacturer 1	AB1	4/10

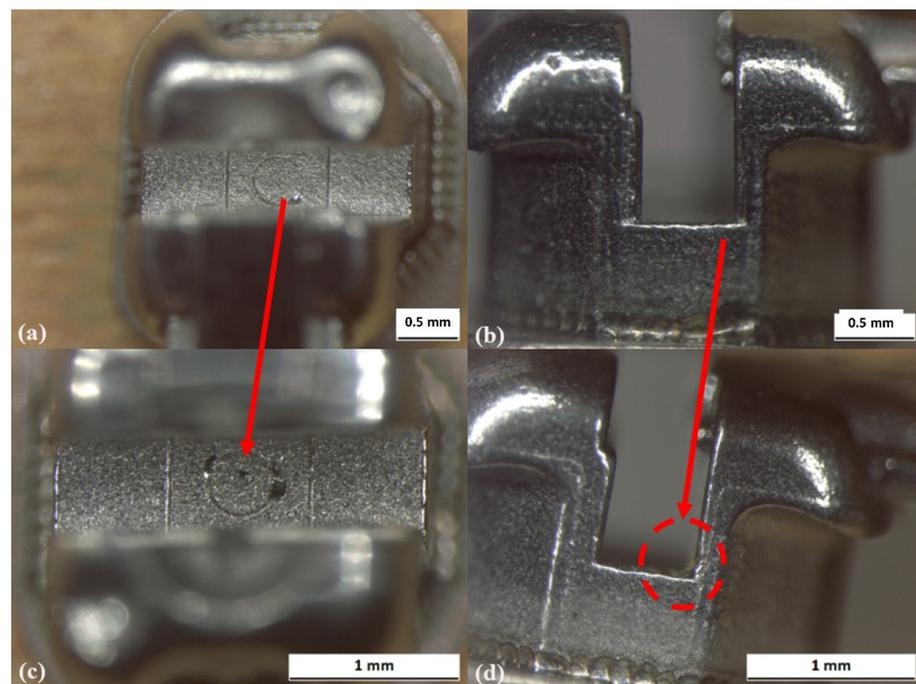


Figure 5. O-Eyes bracket (OO DENTAL) in top and side view: (a,b) before the test; (c,d) after the test.

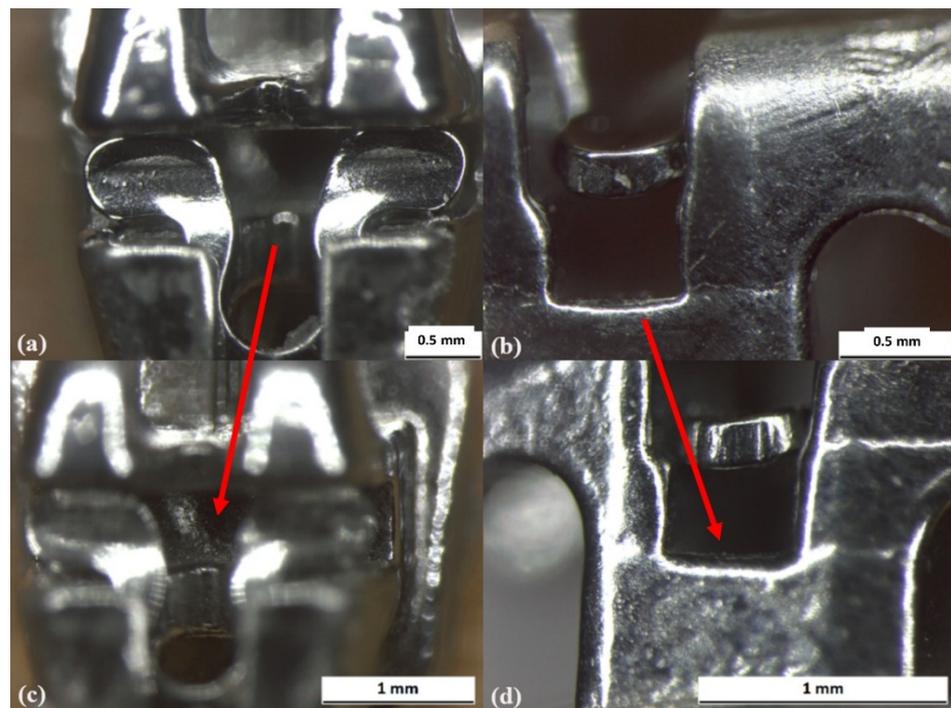


Figure 6. Mistral Plus bracket (Micerium Orthodontics) in top and side view: (a,b) before the test; (c,d) after the test.

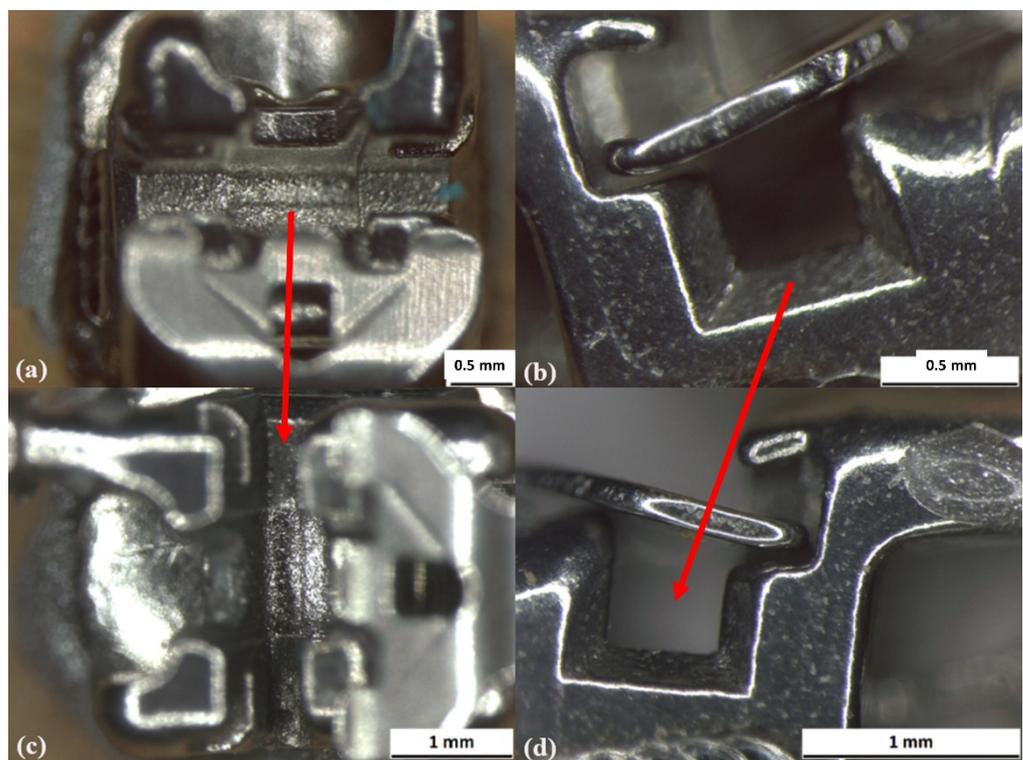


Figure 7. Empower bracket (American Orthodontics) in top and side view: (a,b) before the test; (c,d) after the test.

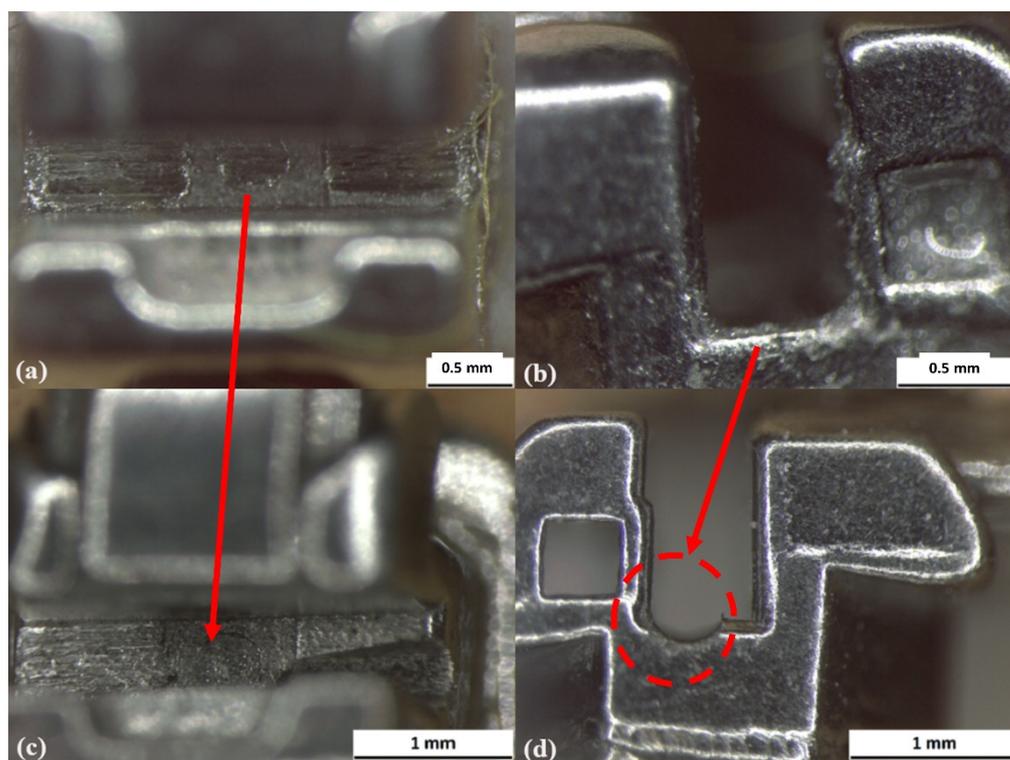


Figure 8. SB1 bracket (Manufacturer 1) in top and side view: (a,b) before the test; (c,d) after the test.

The XRF results and the overall evaluation for self-ligating brackets are shown in Tables 8 and 9, respectively.

Table 8. XRF Self-ligating bracket results. Percentage by weight.

Chemical Element	O-Eyes	Mistral Plus	Empower	SB1
Cobalt (Co)			20.1	0.18
Chromium (Cr)	15.9	14.5	19.6	17.2
Iron (Fe)	68.6	52.1	21.3	72.6
Phosphorus (P)		0.16		
Manganese (Mn)		0.22		0.65
Molybdenum (Mo)		0.051	5.95	0.13
Nickel (Ni)	3.64	20.1	31.3	4.41
Niobium (Nb)	0.23	0.23	0.11	0.24
Copper (Cu)	3.25	2.46	0.58	3.73
Silicon (Si)	8.06	1.9	0.66	0.78
Titanium (Ti)		6.98	0.45	
Vanadium (V)	0.04			0.051
Sulfur (S)		2.11		0.047

Table 9. Self-ligating brackets overall rating.

Company	Commercial Name	Overall Rating
OO DENTAL	O-Eyes	9/10
Micerium Orthodontics	Mistral Plus	7/10
American Orthodontics	Empower	6.5/10
Manufacturer 1	SB1	5/10

The very high presence of nickel on Empower (31.3%) and Mistral Plus (20.1%) is highlighted. Iron is also present in high quantities. The percentage values of chromium and copper are similar for all the brackets analysed.

3.3. Conventional Brackets

The Vesper Plus bracket showed traces of wear inside the slot (Figure 9). The LP Low-Profile bracket also exhibited minor generalized wear of the slot (Figure 10). The CB1 mini bracket had excessive slot wear (Figure 11). The XRF analysis and the overall score for each bracket studied were reported in Tables 10 and 11, respectively. A lower percentage of nickel (4.58%) is found in the Vesper Plus bracket. Furthermore, similar amounts of chromium and copper and high iron values are found in all the brackets studied.

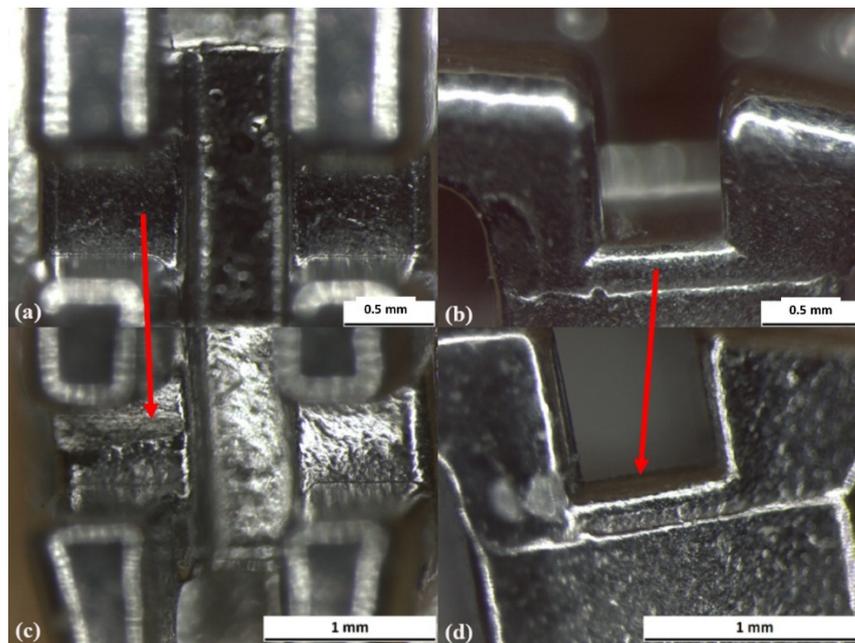


Figure 9. Vesper Plus bracket (Micerium Orthodontics) in top and side view: (a,b) before the test; (c,d) after the test.

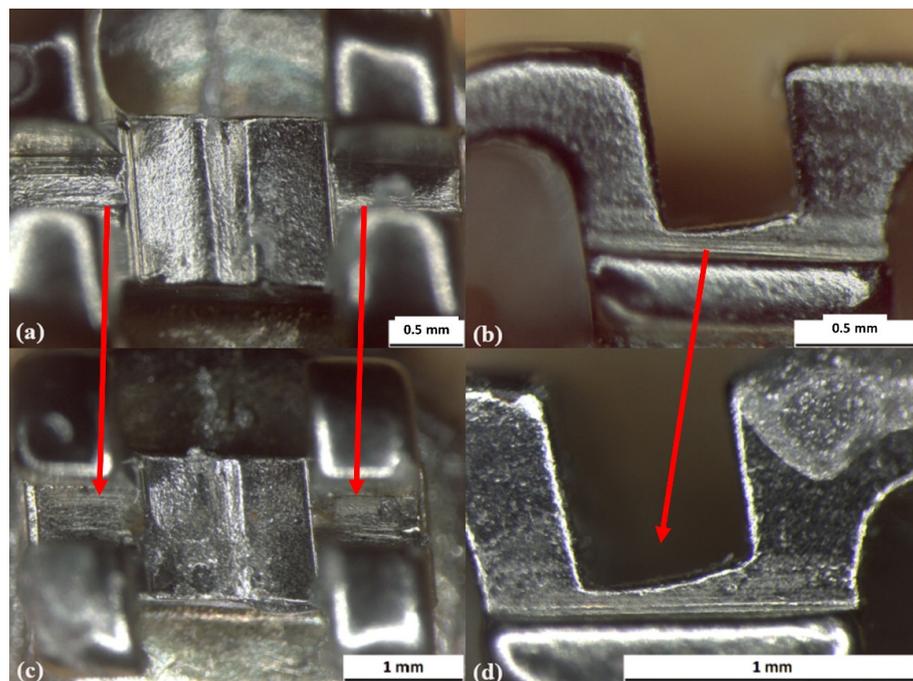


Figure 10. LP bracket (American Orthodontics) in top and side view: (a,b) before the test; (c,d) after the test.

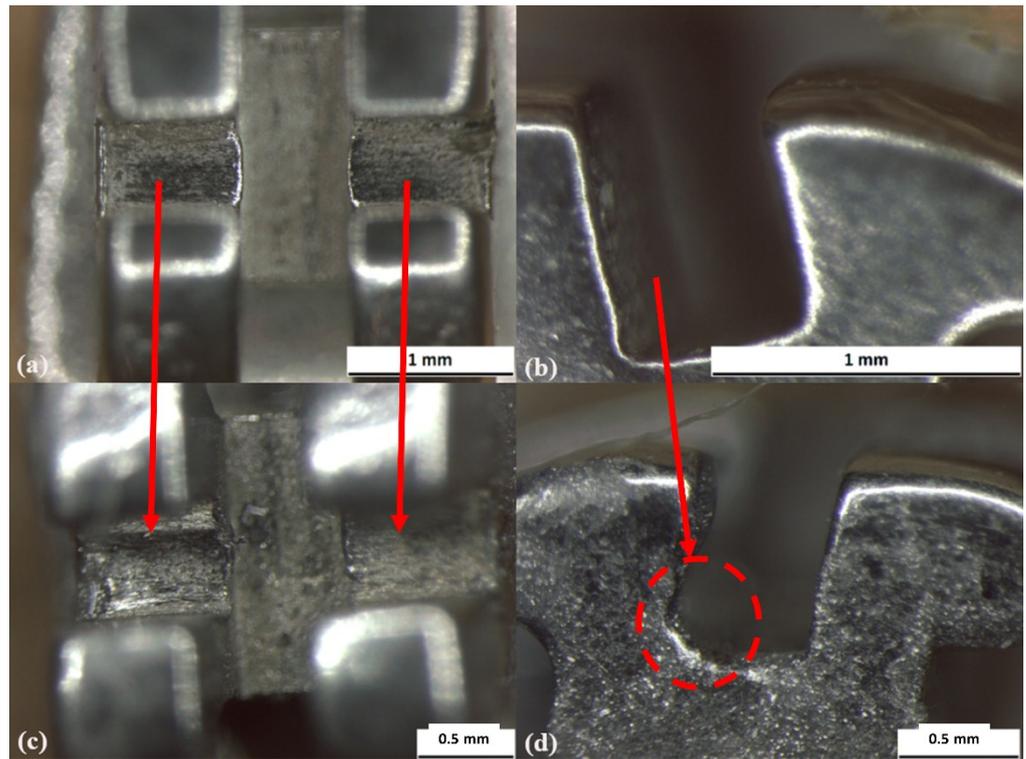


Figure 11. CB1 bracket (Manufacturer 1) in top and side view: (a,b) before the test; (c,d) after the test.

Table 10. XRF results of conventional brackets. Percentage by weight.

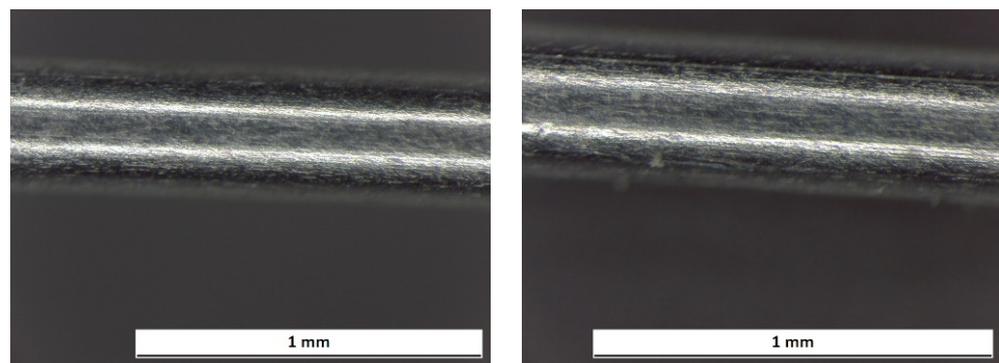
Chemical Element	Vesper Plus	LP	CB1
Cobalt (Co)		0.18	0.21
Chromium (Cr)	17.2	14.1	16.5
Iron (Fe)	73.5	65.8	70.9
Manganese (Mn)		0.44	0.5
Molybdenum (Mo)	0.04	0.94	0.09
Nickel (Ni)	4.58	8.27	7.52
Niobium (Nb)	0.31	0.47	0.17
Copper (Cu)	3.83	4.3	3.37
Silicon (Si)	0.058	1.26	0.47
Tin (Sn)		0.18	
Titanium (Ti)		0.3	
Tungsten (W)		0.11	
Vanadium (V)	0.31	0.04	0.077
Sulfur (S)	0.04	3.52	0.083

Table 11. Conventional brackets overall rating.

Company	Commercial Name	Overall Rating
Micerium Orthodontics	Vesper Plus	8.5/10
American Orthodontics	LP	7.5/10
Manufacturer 1	CB1	4/10

3.4. NiTi Archwires

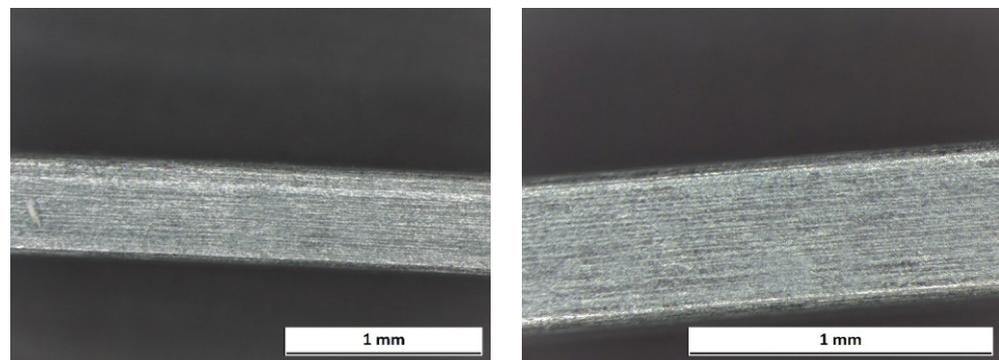
The NiTi Memory wire showed excellent wear behaviour following the test (Figure 12). The Spektra NT Plus wire also exhibited excellent tribological behaviour (Figure 13). The Manufacturer 2 superelastic archwire showed a moderate tribological behaviour (Figure 14). The XRF results are shown in Table 12, while the overall rating is reported in Table 13.



(a)

(b)

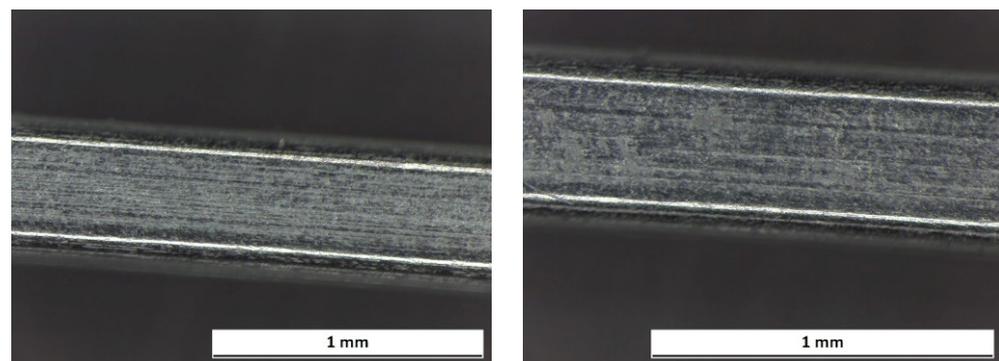
Figure 12. NiTi Memory archwire (American Orthodontics) in top view: (a) before the test; (b) after the test.



(a)

(b)

Figure 13. Spektra NT Plus archwire (Micerium Orthodontics) in side view: (a) before the test; (b) after the test.



(a)

(b)

Figure 14. Superelastic archwire (Manufacturer 2) in side view: (a) before the test; (b) after the test.

Table 12. XRF results of NiTi archwires. Percentages by weight.

Chemical Element	NiTi Memory	Spektra NT Plus	Superelastic
Molybdenum (Mo)	0.19		
Nickel (Ni)	58.3	58	57.8
Titanium (Ti)	41.6	42	42.2

Table 13. Overall rating of NiTi archwires.

Company	Commercial Name	Overall Rating
American Orthodontics	NiTi Memory	9/10
Micerium Orthodontics	Spektra NT Plus	9/10
Manufacturer 2	NiTi SE Upper 0.016 × 0.022	8.5/10

3.5. Thermal Archwires

The Spektra TH Plus wires exhibited good tribological behaviour (Figure 15). The Tanzo archwires did not show excessive deterioration of the surface after the test (Figure 16). The NiTi–Cu wire showed no evident traces of wear (Figure 17). Tables 14 and 15 show, respectively, the results of the XRF analysis and the overall evaluation of the archwires under study. High nickel percentage values are reported. In addition, the quantities of copper are similar among the studied components.

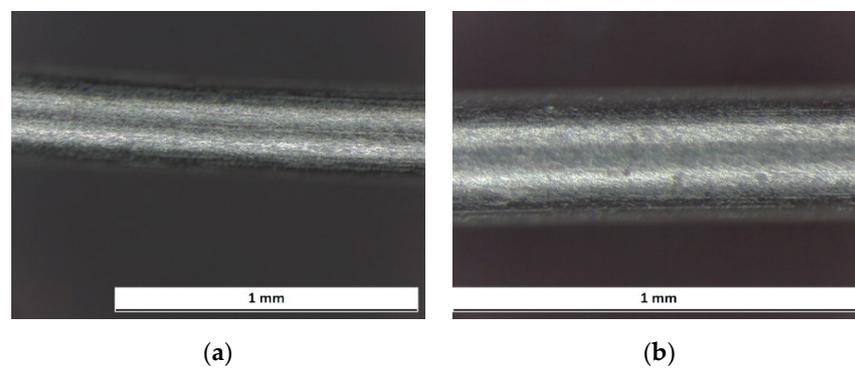


Figure 15. Spektra TH Plus archwire (Micerium Orthodontics) in top view: (a) before the test; (b) after the test.

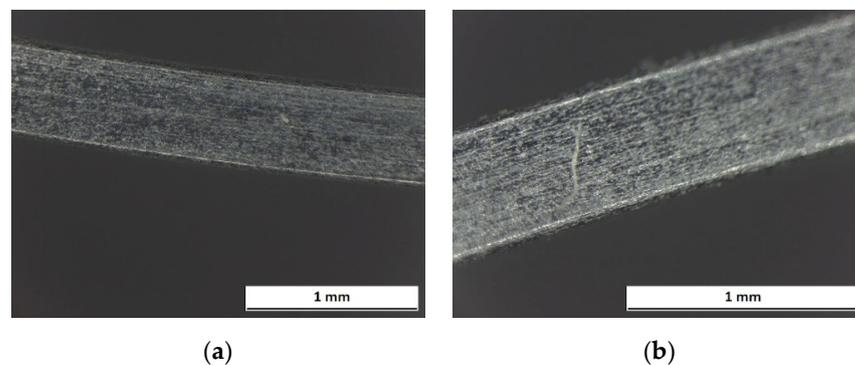


Figure 16. Tanzo archwire (American Orthodontics) in top view: (a) before the test; (b) after the test.

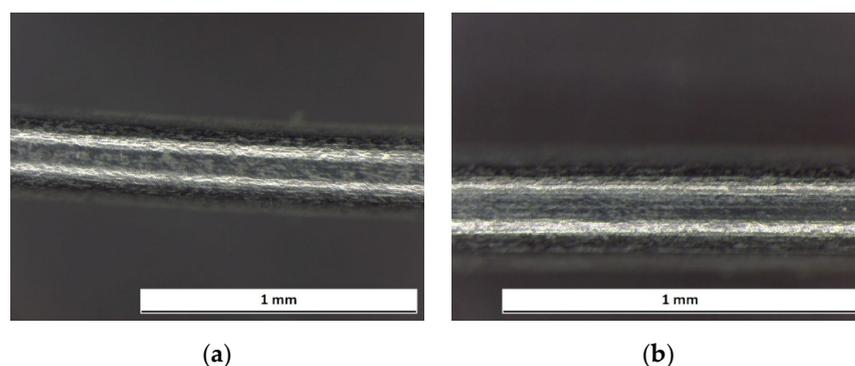


Figure 17. NiTi–Cu Thermal archwire (Manufacturer 2) in top view: (a) before the test; (b) after the test.

Table 14. XRF results of Thermal archwires. Percentages by weight.

Chemical Element	Spektra TH Plus	Tanzo	NiTi-Cu Thermal
Chromium (Cr)		0.16	0.17
Molybdenum (Mo)		0.021	
Nickel (Ni)	52.5	52.1	52.7
Copper (Cu)	5.6	5.96	4.87
Titanium (Ti)	41.9	41.6	42.3

Table 15. The overall rating of Thermal archwires.

Company	Commercial Name	Overall Rating
Micerium Orthodontics	Spektra TH Plus	8/10
American Orthodontics	Tanzo	7.5/10
Manufacturer 2	NiTi-Cu Thermal	7/10

4. Discussion

Wear of materials within the oral cavity has been the main topic for biomaterial science and technology. The combined action of biological factors can cause the biodegradation of these materials, reducing their clinical performance [38]. Compromising the integrity of orthodontic components leads to morphological changes and surface alterations due to wear, deformation, and roughness [39–41]. Wear caused by friction must be minimized to avoid release of chemical elements into the oral environment due to the produced debris [42]. However, it is difficult to adequately simulate the in vivo environment with current in vitro research methodologies.

Brackets must be of adequate hardness and strength to withstand the frictional force within the wire-slot system. The literature reports little information regarding the comparison of the wear effects of brackets and wires before and after their use. Our research considered monocrystalline sapphire (Radiance, Zephyr, AB1), passive self-ligating (Empower, Mistral Plus, O-Eyes, SB1), and conventional metal brackets (LP, Vesper Plus, CB1), while the archwires analysed were superelastic NiTi, thermal NiTi, and thermal Cu–NiTi.

It has been extensively demonstrated that the smooth surfaces of the SS brackets facilitate the sliding of the archwire within the slot [19,20]. On the other hand, aesthetic ceramic brackets have a higher resistance to sliding due to surface roughness [12,19,22]. Monocrystalline sapphire brackets have lower frictional values than polycrystalline alumina brackets [21]. However, the literature reports that resistance to sliding was higher in monocrystalline ceramic brackets than in polycrystalline ceramic brackets in a dry environment [43,44]. In the context of self-ligating brackets, passive brackets minimize frictional resistance compared to active brackets, especially when NiTi and beta-titanium archwires are used [45]. Regarding the archwires, there is no difference in the effectiveness of dental alignment between the superelastic NiTi wires and the heat activated Cu–NiTi wires [46]. However, in low-friction mechanics such as self-ligating brackets, thermal archwires are preferred over superelastic ones in the early stages of fixed orthodontic treatment [47]. In our study, microscopic analysis showed that the orthodontic components analysed underwent superficial alterations of varying degrees during the tribological treatments. These different results could be related to the tribological, physical, and electrochemical properties of each material and to the manufacturing procedures of the different types of orthodontic accessories analysed (brackets and archwires).

The release of wear products can be analysed using different methodologies [48,49], and this can make it difficult to compare the results with those of other studies. Furthermore, several researches have highlighted only the superficial changes of the orthodontic wires using scanning electron microscopy (SEM) without evaluating the quantity of ions released [50,51]. In this study, X-ray fluorescence spectroscopy (XRF) analysis was also performed for the chemical assessment of ions released from wear products.

Cases of allergy or adverse reactions have been observed in patients treated with fixed orthodontic appliances for the release of metal ions in the oral cavity, mainly due to the quantities of nickel (Ni) released [49,52]. The released quantities of metal ions have a low cytotoxicity; however, over time, they can accumulate in the oral tissues [53], causing adverse reactions in subjects with already known allergies [54].

Among the aesthetic brackets, the Zephyr maintains discrete aesthetic properties, as it presents a modest wear inside the slot and contains a very low amount of Ni (0.009%) compared to the other accessories studied. Furthermore, all the aesthetic brackets analysed have insignificant or zero percentages of chromium and copper. Despite the optimal behaviour of the Empower self-ligating bracket during the tribological test, the O-Eyes passive self-ligating bracket scored better than the other brackets in the same group. The cause is to be found in the significant difference in the amount of Ni (31.3% of Empower vs. 3.64% of O-Eyes). The self-ligating Mistral Plus also exhibits good tribological behaviour but contains a high percentage of Ni (20.1%). Finally, the amounts of iron, chromium, and copper are similar among the self-ligating brackets studied, except the Empower, which has lower percentages of iron and copper (21.3% and 0.58%, respectively). Within the different types of conventional brackets, the Vesper Plus bracket has the highest score both for the minimum wear found and for the low quantity of nickel. It should be noted that Vesper Plus contains a slightly higher percentage of iron (73.5%). The amounts of chromium and copper are similar in all conventional brackets. Furthermore, the Vesper Plus bracket features an overall rating compared to the Zephyr and O-Eyes brackets.

Depending on the manufacturer, NiTi orthodontic archwires have nickel and titanium contents that can vary from 51.3 to 57% and 43 to 48.7%, respectively [55,56]. In Cu–NiTi alloy wires, the Cu content varies from 5.5 to 6.9% [57]. Among the NiTi archwires, the Ni-Ti Memory and Spektra NT Plus wires of AO and Micerium Orthodontics, respectively, show excellent tribological behaviour. Manufacturer 2 NiTi SE archwire scored the lowest in the overall rating due to the increased wear found after the tribological test. Within the group of thermal archwires, the Micerium Orthodontics Spektra TH Plus wire is the best for its behaviour after the wear test. It also does not contain chromium; however, this element is present in low concentrations in the other archwires studied. The percentage amount of nickel and copper are similar in all the three wires.

5. Conclusions

Among the aesthetic brackets on the market, the monocrystalline sapphire brackets with coated bases, such as Zephyr, are more resistant to the wear processes caused by the applied frictional forces. The metal brackets studied (self-ligating and conventional) contain similar amounts of chromium, iron, and copper. However, significant levels of nickel were found in some types of self-ligating brackets, influencing the overall final evaluation. Finally, superelastic Ni-Ti archwires do not show significant wear surface alterations compared to thermal wire, thus obtaining a better evaluation. Rapid and simple evaluation of wear behaviour and chemical elements can guide clinicians in identifying the best treatment for each patient.

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