*Original research*

*Title page*

EVALUATION OF THE MECHANICAL PROPERTIES AND SURFACE TOPOGRAPHY OF AS-RECEIVED, IMERSSED AND AS-RETRIEVED ORTHODONTIC ARCHWIRES

ABSTRACT

Backgrounds and Aims. This experimental study mainly aims at comparing the most important mechanical properties of the new orthodontic arch wires, of those immersed in fluorinated solution, of the as-retrieved ones and of the intra-oral used ones.

Methods. A total of 270 arch wires were tested, using tensile testing and three-point bending tests. The tested archwires were made of Stainless Steel, Nickel Titanium, Beta-Titanium and physiognomic covered Nickel Titanium. The tested arch wires were subjected to three types of treatments: immersion into fluorinated solution, immersion into carbonated drinks and intra-oral use.

Results. The immersion cause variations of the activation and deactivation forces of all arch wires. The most affected arch wires, in terms of bending characteristics are the intra-oral used ones.

Conclusions. The affectation of mechanical properties of the orthodontic arch wires by immersing them into fluorinated solutions and soft drinks could not be statistically demonstrated, though there is a tendency to reduce them.

KEYWORDS: orthodontic archwire; Nickel Titanium; stainless steel; beta-titanium; mechanical testing.

1. BACKGROUND AND AIMS

The orthodontic biomechanics is based on the principle of storage of elastic energy and its conversion into mechanical energy during the tooth movement [1]. The optimal control of the tooth movement requires the application of a special force system, by using some accessories elements like the arch wires. Despite of the considerable number of existing commercial brands and their vehement advertising, the most used dental arches remain the stainless steel (SS) arch wires, nickel titanium (NiTi) ones and beta-titanium (β-Ti) ones. In addition to this, the metal aesthetic coated arch wires and the physiognomic non-metal coated arch wires are more and more known [1].

In the last decades numerous studies [2-9,10,11,12] are focused on evaluating the mechanical and surface properties of new arch wires. During the orthodontic treatment, the arch wires are exposed to the action of different acid or alkaline substances and the changes due to these chemicals on the surface and structure and, therefore, on the clinical efficacy of metal alloys are less known. Also, the difficulty of reproduction in vitro of the multitude and of the variety of factors present in the oral cavity during the orthodontic treatment impede even more the transposition and interpretation of results in the orthodontic biomechanics.

One of the keys to success of the orthodontic treatment is to maintain the oral hygiene and the caries control [13-15]. Thus, the daily use of the fluoride preparations on the recommendation of an orthodontist is a prophylactic method often used to prevent white spot lesions [14,15]. However, it was shown that the fluoride ions of the fluoride preparations may cause corrosion phenomena, the color change of the orthodontic arch wires and the alteration of the mechanical properties, especially the frictional properties [13]. Also, there are numerous studies [13,16,17-19,20-30] concerning how the fluoride concentration, the time exposure and the acidity of the solution cause changes to the arch wires properties. Studies related to soft drinks [31-33] are focused on their effect on the enamel structure and on the interference with the bracket adhesion[31,32] and only a few of them evaluate their effect on the mechanical properties of the arch wires[ 33].

During the orthodontic treatment, the orthodontic arch wires are subject to numerous factors and variables present into the oral cavity [34]. The assessment of the surface morphology of these intra-orally used arch wires was the purpose of numerous studies [35-41]. However, there are only a few works in which the study the mechanical properties of the arch wires used in vivo prevail. The bending testing was conducted by Elavyan [35], but only on aesthetic covered arch wires collected from patients with minor crowding, without any extractions of premolars treated with fixed devices. Also, the studies of Eliades [34,39] tried to determine whether the complex conditions of the oral cavity lead to the deterioration of the surface properties of the arch wires and also to correlate the changes in topography with those of structural composition.

The surface topography of the orthodontic arch wires is an essential property, having the ability to influence the mechanical characteristics, the appearance, corrosion and their biocompatibility. The result of the surface structure depends on several factors including: the alloy used in manufacturing, the complex manufacturing process and the finishing treatment of the surface [42, 43].

Thus, we considered useful the writing of a study which will include the analysis of the orthodontic intra-orally used arch wires in comparison with the new ones and those used in vitro. This experimental study mainly aims at highlighting and comparing the most important mechanical properties of the new (as-received) orthodontic arch wires, of those immersed in fluorinated solution, of the as-retrieved ones and of the intra-orally used ones (made of SS, NiTi, β-Ti and aesthetic NiTi). A microscopic characterization of these arch wires was also intended, in terms of surface topography. The null hypothesis is that immersion and intra-oral use does not alter the mechanical properties and the surface topography of these arch wires.

2. MATERIALS AND METHODS

The arch wires tested were: NiTi and SS of 0.016 inch and of 0.016x0.022 inch, as well as β-Ti of 0.016x0.022 inch and physiognomic NiTi (Phys-NiTi) of 0.016 inch. A total of 270 arch wires were mechanically tested. All arch wires were taken from the same manufacturer, GAC Company (GAC-DENTSPLY Corporate, York, USA) and from the same batch, to eliminate the possible variations due to different batches. The arch wires were divided into three categories, as follows: new arch wires, immersed arch wires and intra-orally (IO) used arch wires.

The new arch wires were mechanically tested immediately after removing the protective packaging material. The immersed arch wires were placed in hermetically sealed plastic containers and then incubated at 37°C for 7 days in the laboratory thermostat (WB Falc M5, Falc Instruments Italy). The permanent monitoring of the temperature was made with a digital thermometer and there were no registered variations bigger then ±1°C.

The solutions used for immersion had the following composition:

• Coke: phosphoric acid, sugar, carbon dioxide, flavors, pH=2.6

• Local fluorination agent in the form of a gel (Home care fluoride gel, Dental Technologies, Illinois, USA): 0.4% stannous fluoride, ascorbic acid, citric acid, flavors, glycerin and carbomer.

The amount of immersion solution in each container was 4 ml, to ensure the full immersion of the arch wires. At the same time, every 24 hours the solutions were changed. At the end of the period of immersion, the arch wires were washed with distilled water and placed in new packages individually marked.

The arch wires used in vivo were collected from 21 patients treated with fixed orthodontic devices by the orthodontist. The criteria of patient selection were:

* The treatment with fixed maxillary and mandible device, brackets used according to Roth prescription, the use of a slot of 0.018 inch, metal or elastic ligatures
* Close age of patients (14-25 years old)
* The lack of labio-maxillo-palatal clefts or of other craniofacial syndromes
* Cooperating patients
* Good or satisfactory oral hygiene
* The lack of general affections which may quantitative and qualitative influence the salivary secretion (E.g. xerostomia, diabetes etc.)

After collection, the arch wires were washed with distilled water and placed in packs labeled with the name of the patient, the size and type of the arch (alloy, the upper or lower arch), the application and removal date of the arch. The arch wires were grouped into two categories, depending on the intra-oral time of use, as follows:

a. Intra-oral arch wires used for 4-6 weeks (having the call sign IO-1 month)

b. Arch wires used for more than 6 weeks into the oral cavity (having the call sign IO-2 months)

The determination of mechanical characteristics was performed by tensile test and three-point bending test, using an Instron universal machine (Instron, type 3366 Norwood, MA) equipped with Instron Bluehill 2 software. For each type of arch there were 5 specimens subjected to the test.

2.1. Tensile test

In order to achieve the tensile test, the ends of the specimens were fixed into the jaws of the testing machine, so that the distance between the reference marks (gauge length) was 40 mm. The moving speed of the crosshead was set at 1 mm/min. The tensile-strain diagrams (stress-strain) were obtained and the yield strength (YS), the ultimate tensile strength (UTS) and the modulus of elasticity (E) were calculated. The yield strength was calculated for a specific deformation of 0.2%. The tensile testing of the NiTi arch wires of 0.016 inch physiognomic recovered could not be achieved. We were unable to exactly determine the break resistance value while using tensile tests due to some technical difficulties, these arch wires sliding out from the fixing bracket. Unlike the new arch wires, to which the distal portion attached to the clamping jaws of the test machine was not covered by the aesthetic coating, to those placed into the oral cavity, this portion of the arch was cut out. Thus, when using the tensile test, the Teflon coating broke away from the metal surface of the arch. The intra-orally used β-Ti arch wires were not sufficient in number to be tested for tensile strength.

2.2. The Bending Test

The bending characteristics (activation and deactivation forces) were determined by using a three-point bending test (Miura et al., modified by Krishnan and Kumar[2,9]. In order to be tested, the arch wires were inserted into the slot of some edgewise type brackets (3B STD Edgewise, GAC International TM), fixed with elastic ligatures, glued on an aluminum backing, specially conformed for the bending test. The brackets subject to the bending test were placed so that the inter-brackets segment distance was 14 mm. The aluminum support was attached to the lower jaw of the testing machine. To the upper jaw of the testing machine a metal blade with a curvature of 1 mm at the end was attached. Using this blade, the bending test of the arch wires was performed in their middle portion. From each specimen the relatively straight, distal portions were tested. The NiTi and physiognomic NiTI arch wires were bent up to 1 and 4 mm respectively, while those made of SS were bent only up to 1 mm. We didn’t found it useful to bend them at higher values, as these arch wires are not subject to bigger bending values into the oral cavity.

The statistical analysis was performed using the Excel program for Windows and the test used was the t Student test, *p≤*0.05 significance level. The study of the surface topography was done by Scanning Electronic Microscope (SEM) and optical analysis. A FEI Quanta 3D scanning electronic microscope was used to highlight the micro-morphological characteristics of the surface of the arch wires. The magnifications used were from x200 to x3000. The optical microscope (MO) used to the study the arch wires was an Olympus GX 51.

Basically, two specimens from each type of arch, randomly chosen, both new (as received) as well as the immersed ones and the intra-orally used ones were subjected to microscopic examinations. From each specimen the straight distal parts were cut out (two), at approximate 20 mm. One of the fragments was analyzed with the optical microscope and the second one with an electronic microscope.

3. RESULTS

3.1. Mechanical Testing

The results of the tensile test upon the new and immersed arch wires as well as the level of significance (p) obtained from a comparative statistical analysis between new and immersed arch wires are shown in Tables I, II and III.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Property** | **NiTi**  **New 0.016x0.022** | **Niti**  **Coke 0.016x0.022** | **Niti**  **Fluorine 0.016x0.022** | **NiTi**  **New 0.016** | **Niti**  **Coke 0.016** | **Niti**  **Fluorine 0.016** |
| Yield strength | 320.79±30.87 | 374.89±15.  p=0.0543 | 97368.68±4.08  p=0.0708 | 334.03±9.8 | 383.01±18.27  p=0.0149 | 358.63±12.07  p=0.0519 |
| Ultimate Tensile strength | 1252.8±23.14 | 1324.12±23.53  p=0.0200 | 1318.1±12.37  p=0.0125 | 1257.31±25.34 | 1320.24±15.56  p=0.0214 | 1268.53±9.44  p=0.5121 |
| Elastic modulus | 24837.42  ±1227.46 | 28097.99±885.46  p=0.0202 | 28375.64±345.05  p=0.0086 | 30187.38  ±1932.17 | 33858.24  ±1019.67  p=0.3740 | 31348.77  ±562.5  p=0.3740 |

Table I. The results of the tensile tests upon the new and immersed NiTi arch wires

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Property** | **SS**  **New 0.016x0.022** | **SS**  **Coke 0.016x0.022** | **SS**  **Fluorine 0.016x0.022** | **SS**  **New 0.016** | **SS**  **Coke 0.016** | **SS**  **Fluorine 0.016** |
| Yield strength | 1766.7±189.9 | 2064.57±40.49 p=0.0273 | 2065.56±9.91 p=0.5496 | 2188.11±58.13 | 2261.91±14.94 p=0.0250 | 2283.86±43.95 p=0.0187 |
| Ultimate Tensile strength | 1820.4±163.35 | 2068.24±36.01 p=0.0138 | 2065.56±9.91 p=0.0117 | 2188.11±58.13 | 2261.91±14.94 p=0.0250 | 2283.86±43.95 p=0.0187 |
| Elastic modulus | 133264.79  ±6254.9 | 113622.85  ±1609.06  p=0.0004 | 111684.27  ±198.2  p=0.0007 | 113279.85  ±5514.65 | 120662.98  ±1161.13  p=0.0190 | 125862.61  ±2145.38  p=0.0014 |

Table II. The results of the tensile tests upon the new and immersed SS arch wires

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Property** | **β-Ti**  **New**  **0.016x0.022** | **β-Ti**  **Coke 0.016x0.022** | **β-Ti**  **Fluorine 0.016x0.022** | **Fiz-NiTi**  **New 0.016** | **Fiz-NiTi**  **Coke 0.016** | **Fiz-NiTi**  **Fluorine 0.016** |
| Yield strength | 1156.71±30.37 | 1307.8±16.54 p=0.0049 | 1312.38±18.44 p=0.0051 | 200.99±11.09 | 180.12±28.05 p=0.4072 | 222.4±7.43 p=0.1515 |
| Ultimate Tensile strength | 1156.71±30.37 | 1307.8±16.54 p=0.0049 | 1312.38±18.44 p=0.0051 | 649.34±98.01 | 794.86±139.55 p=0.2989 | 844.61±152.39 p=0.2669 |
| Elastic modulus | 40975.26  ±2049.19 | 46798.69  ±471.72 p=0.0143 | 46682.29  ±304.68 p=0.014 | 23291.33  ±344.62 | 19951.31  ±3042.69 p=0.2383 | 23496.29  ±2058.55 p=0.9022 |

Table III. The results of the tensile tests upon the new and immersed -Ti and Phys -NiTi arch wires

The activation and deactivation values of the forces obtained from the bending test are graphically presented in Fig. 1 for the Phys-NiTi arch wires, in Fig. 2 for the 0.016x0.022 NiTi ones, in Figs. 3 and 4 for the SS ones and tabular given for the round NiTi and rectangular β-Ti arch wires (Tables IV and V).

|  |  |  |  |
| --- | --- | --- | --- |
| **NiTi 0.016** | **New arch wires** | **Fluorine immersed arch wires** | **Coke immersed arc wires** |
| Loading 0.5 mm | 0.86±0.225 | 1.16±0.109 | 1.41±0.124 |
| Loading 1 mm | 2.44±0.192 | 2.63±0.195 | 2.83±0.117 |
| Unloading 0.5 mm | 0.55±0.207 | 0.69±0.064 | 0.96±0.121 |
| Loading 2 mm | 3.46±0.301 | 3.65±0.029 | 3.62±0.147 |
| Loading 4 mm | 4.38±0.343 | 4.83±0.149 | 4.68±0.051 |
| Unloading 2 mm | 0.73±0.165 | 0.59±0.25 | 0.98±0.06 |

Table IV. The bending test results of 0016 NiTi new and immersed arch wires

|  |  |  |  |
| --- | --- | --- | --- |
| **β-Ti 0.016x0.022** | **New** | **Fluorine** | **Coke** |
| Loading 2 mm | 13.43±0.226 | 20.68±0.157 | 17.62±0.659 |
| Loading 4 mm | 14.21±0.099 | 26.41±0.511 | 21.76±0.14 |
| Unloading 2 mm | 1.51±0.117 | 1.31±0.38 | 0.14±0.24 |

Table V. The bending test results at 4 mm for the new and immersed β- Ti 0.016x0.022 arch

The results obtained from the tensile test for 0.016 inch arch wires and 0.016x0.022 inch NiTi are listed in Table VI. In the case of 0.016 inch NiTi arch wires, we notice a decrease in values of the three parameters but not a significant one from the statistical point of view.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Arch wire** | **Treatment** | **Yield strength** | **Tensile strength** | **Elastic modulus** |
| NiTi  0.016 | New arch wires  IO - 1 month | 334.03±9.8  322.26±51.24  p=0.7169 | 1257.31±25.34  1210.91±70.17  p=0.3327 | 30187.38 ±1932.17  27069.04±2410.55  p=0.1268 |
| NiTi  0.016 | New arch wires  IO – 2 months | 334.03±9.8  306.26±10.11  p=0.0268 | 1257.31±25.34  1232.48±28.22  p=0.3202 | 30187.38±1932.17  27286.98±4088.46  p=0.3288 |
| NiTi 0.016x0.022 | New archwires  IO - 1 month | 320.79±30.87  320.63±60.39  p=0.9969 | 1252.8±23.14  1180.53±206.88  p=0.5800 | 24837.42±1227.46  23164.29±3964.42  p=0.5234 |
| NiTi 0.016x0.022 | New archwires  IO – 2 months | 320.79±30.87  221.19±7.3  p=0.0055 | 1252.8±23.14  1170.58±14.38  p=0.0064 | 24837.42±1227.46  19881.19±1189.16  p=0.0073 |

Table VI. The tensile test results for the intra-orally used NiTi arch wires

The IO use of NiTi 0.016x0.022 inch arch wires results in the reduction of the values of the three parameters, especially when using the arch wires on periods longer than 6 weeks (Table VI).

In the case of SS steel 0.016 inch arch wires the values of the three parameters were significantly decreased both after IO-1 month usage as well as in the case of the IO-2 months (Table VII).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Arch wire** | **Treatment** | **Yield strength** | **Tensile strength** | **Elastic modulus** |
| SS 0.016 | New archwires  IO – 1 month | 2188.11±58.13  1992.88±74.47  p=0.0129 | 2188.11±58.13  2012.44±28.67  p=0.0030 | 113279.85±5514.65  98089.55±10957.2  p=0.0365 |
| SS 0.016 | New archwires  IO – 2 months | 2188.11±58.13  1987.33±10.86  p=0.0058 | 2188.11±58.13  1987.33±10.86  p=0.0058 | 113279.85±5514.65  96331.2±3426.74  p=0.0111 |
| SS 0.016x0.022 | New archwires  IO – 2 months | 1766.7±189.9  1896.38±102  p=0.4845 | 1820.4±163.35  1896.71±72.12  p=0.5002 | 133264.79±6254.9  75448.37±3704.84  p=0.0001 |

Table VII. The results of the tensile tests of the SS intra-orally used arch wires

Elastic modulus values of 0.016x0.022 inch SS IO-2 months arch wires decreased significantly in comparison with those of new and immersed arch wires. The values of the yield strength and of the tensile strength for the same arch wires in comparison with those for the new arches did not significantly changed.

Concerning the bending test, the results are shown in Fig. 5. The activation and deactivation values of forces for intra-orally used arch wires were compared with the values obtained from testing the new arch wires of a corresponding size.

For the rectangular NiTi intra-orally used arch wires used for more than 6 weeks a significant decrease in deactivation force was noticed from 5.11 to 3.39 N (Table VIII).

|  |  |  |  |
| --- | --- | --- | --- |
| **NiTi 0.016** | **New archwires** | **IO – 1 month** | **Comparison** |
| Loading 0,5 mm | 0.86±0.225 | 1.26±0.114 | p=0.0509 |
| Loading 1 mm | 2.44±0.192 | 2.47±0.353 | p=0.9156 |
| Unloading 0,5 mm | 0.55±0.207 | 0.6±0.185 | p=0.7756 |
| Loading 2 mm | 3.46±0.301 | 3.39±0.169 | p=0.7250 |
| Loading 4 mm | 4.38±0.343 | 4.72±0.105 | p=0.1630 |
| Unloading 2 mm | 0.73±0.165 | 0.45±0.127 | p=0.0576 |

|  |  |  |  |
| --- | --- | --- | --- |
| **NiTi 0.016x0.022** | **New archwires** | **IO 2 months** | **Comparison** |
| Loading 0,5 mm | 4.74±0.265 | 3.04±0.01 | p=0.0033 |
| Loading 1 mm | 7.5±0.246 | 4.71±0.007 | p=0.0006 |
| Unloading 0,5 mm | 3.35±0.173 | 0.35±0.16 | p=0.0003 |
| Loading 2 mm | 9.96±0.198 | 9.41±0.705 | p=0.3838 |
| Loading 4 mm | 12.04±0.328 | 13.63±0.989 | p=0.1270 |
| Unloading 2 mm | 5.11±0.073 | 3.39±0.563 | p=0.0266 |

Table VIII. The bending test results of NiTi intra-orally used arch wires

The results obtained from the bending test of SS intra-orally used (Table IX) showed that the values of the deactivation forces at 0.5 mm and 2 mm were 0, significantly lower than in the case of the new arch wires.

|  |  |  |  |
| --- | --- | --- | --- |
| **SS 0.016** | **New archwires** | **IO** | **Comparison** |
| Loading 0.5 mm | 2.08±1.31 | 3.77±0.094 | p=0.0904 |
| Loading 1 mm | 5.98±1.215 | 7.44±0.489 | p=0.1252 |
| Unloading 0.5 mm | 1.56±1.105 | 0±0 | p=0.0705 |

Table IX. The bending test results of SS 0016 intra-orally used arch wires

The esthetic NiTi intra-orally used arch wires of 0.016 inch (Table X) developed activation forces to 2 and 4 mm bigger than the new ones, but, as in the case of the new arch wires, the deactivation force at 2 mm was equal to 0, basically these arch wires not going back after stopping the force application.

|  |  |  |  |
| --- | --- | --- | --- |
| **Phys-NiTi 0.016** | **New archwires** | **IO** | **Comparison** |
| Loading 2 mm | 2.18±0.154 | 2.57±0.136 | p=0.0578 |
| Loading 4 mm | 2.74±0.02 | 4.01±0.396 | p=0.0233 |
| Unloading 2 mm | 0±0 | 0±0.005 | p=0.4950 |

Table X. The bending test results of Phys-NiTi intra-orally used arch wires

3.2. Surface analysis

The figures 6a and 6b present the scanning electron microscopy images and those of the optical microscopy ones for the as-received NiTi new arch wires. Some striations parallel to the long axis of the arches, characteristic for the manufacturing process can be noticed on the surface of the new arch wires. Also, minor circular defects can be observed which provides a marbled appearance, a rough aspect to the surface of the arch wires.

The images of NiTi arch wires immersed into a fluorinated solution and into a soft drink confirmed that the fluorinated solution affects the surface of the NiTi arch wires forming a reaction products layer visible under the optical microscope (Fig. 7a, b). The exposure of the arch wires in the intra-oral environment determines significant changes in their surface topography, with the appearance of porous corrosion areas, friction areas and those in the form of cracks, visible both in SEM (Fig. 7c) and in MO.

The new SS arch wires studied in SEM, reveals various topography but with the constant presence of the striations parallel to the long axis, characteristic of the manufacturing process (drawing) and the presence of micrometer cracks. The immersion of SS arch wires in coke causes the appearance of some dark areas alternating with areas like those on the new arch wires. The fluoride causes corrosion areas in forms of stains. The usage of the SS intra-oral arch wires determined sharp changes of the surface characteristics. The SEM images (Fig. 8a) highlight a growing and significant diversification of the surface defects due both to the handling of the arch wires during their insertion and removing, as well as in the form of a uniform corrosion present on large areas. The frictional corrosion due to frictional forces occurring in the bracket - arch interface is shown in Fig. 8b, while the corrosion of aging with the occurrence of a crack is visible in Fig. 8c.

The new β -Ti arch wires (Fig. 9a) presented a rough surface with many cracks. Out of all metallic arch wires, these arch wires have shown the most irregular surface. Their immersion into coke caused the occurrence of some corrosion areas (Fig. 6.4 b) while the fluoride deepened the fissure defects (Fig. 9c). The use of intra-oral arch wires for a period of about six weeks led to a major damage of the arch wires with the deposition of organic deposits and an obvious increase of the surface roughness (Fig. 9d).

The new phys-NiTi arch wires presented a porous surface structure. The aesthetic coating of these arch wires provided a rough structure with numerous pores of variable sizes and an irregular surface highlighted in the SEM images (Fig. 10a). The immersion of these arch wires into coke determined the growth of the porous defects with a unifying tendency, while the fluoride determined the desquamation of the aesthetic cover, visible in figures 10b and 10c.

A major damage of the aesthetic cover after the intra-oral usage was observed both for the MO and SEM investigations. These images highlight the desquamation on large areas of the aesthetic coating with the uncovering of the metal structure and signs of corrosion on the metal surface (Fig. 11).

4. DISCUSION

Numerous physical, chemical and biological factors may alter the mechanical properties of the orthodontic arch wires. Also, the same factors determine variations in the frictional forces during the sliding biomechanics of the fixed orthodontic treatment. The correlation of the changes in the mechanical properties obtained after the traction test of the new and immersed arch wires emphasizes the importance of the corrosion phenomena localized on the surface of the arch wires and of the need of an accurate knowledge of their production mechanisms.

After this study, no significant changes in the tensile strength of the 0.016 inch NiTi arch wires were observed. This result does not match with those obtained in the studies of Kaneko [18]. In his study, the arch wires that have been evaluated were those of 0.016 inch, immersed into an acid solution of fluoride phosphate, 2% concentration while the incubation time was 60 minutes [18]. The differences in results may be due to different concentration of the solution and the difference in the active substance concentration used. We have used a concentration of 0.4% fluoride for our experiment. Although the incubation time in different studies varies between 1-1.5 hours [16,18] to 1-28 days [43,44], in the present study it was extended over a period of 7 days, corresponding to the usage of an arch wire in an intra-oral medium for about 5 months, using a fluorinated solution twice a day, with an action time of 30 minutes / application.

The effect of fluoride on the modulus of elasticity and on the tensile strength had been evaluated in a study by Hammad [13]. He distinguished no change in these properties after the immersion of the NiTi arch wires, section 0.016, into a 1.1% APF solution and a pH of 5.1.

The studies [16-22] that analyze the degradation of the protective oxide film on the surface of the orthodontic arch wires as a result of their immersion into fluorinated solutions with increased hydrogen absorption and the consequent alteration of their mechanical performances, assume the existence of interference between the martensitic transformation mechanisms and the hydrogen ions. Thus, the increasing of the critical stress of the martensitic transformation by immersing the NiTi arch wires may prevent the development of an appropriate orthodontic force.

In the case of the soft drinks, both the low pH of these solutions, as well as the total amount of acids are important factors in corrosion, as they determine the amount of hydrogen ions available to interact with the passive oxide layer [33]. The increased amount of phosphoric acid present into coke is responsible for the characteristic pattern of corrosion of the NiTi arch wires. Coke, like the fluoride, seems to have a modifying effect on the elastic modulus, with its significant growth in the case of rectangular arch wires (e.g. for the immersed 0.016x0.022 inch NiTi arch wires, the modulus has increased from 24 MPa for the new arch wires to 28 MPa for the arch wires immersed into a fluorinated solution and 28 MPa to those immersed into coke. The effect of the carbonated drinks on mechanical properties of the arch wires has not been investigated in some other studies yet, most of the work focusing on their effect on the surface properties[ 33].

The immersion of β-Ti arch wires with a section of 0.016x0.022 inch into the already mentioned solutions determined an increase of the tensile strength and as well as of the elastic modulus. These results differ from those obtained by Kaneko [18] as he obtained a reduction of the tensile strength of β-Ti arch wires with 5.6% after their immersion into a fluorinated solution. On the other hand, Pernier *et al.* [45] haven’t revealed significant changes in the elastic modulus of Resolve arch wires (Gac Company) after sterilization. The increasing of the values of these parameters cannot be attributed to the immersion solutions; these solutions cannot “improve” the qualities of the arch wires, a more plausible explanation being the variations given by the manufacturing process, even in the case of arch wires from the same batch.

The same authors [45] suggested that the autoclave sterilization at 134˚C for 18 minutes does not determine variations of the elastic modulus in the case of SS arch wires. On the other hand, Kaneko [18] has observed a slight decrease (with 2.6%) of the ultimate tensile strength of the SS arch wires with the size of 0.016 inch. According to their research, hydrogen absorption and corrosion occurrence in the form of cracks on the surface of the SS alloy are closely correlated and determine the alteration of mechanical properties and that of the ultimate tensile strength implicit [18]. However, they admit that this alteration of the mechanical properties is lower in the case of SS alloys when compared to those containing β-Ti and NiTi. These statements are contradictory to those of Eliades *et al*. [38] according to whom corrosion does not affect the mechanical properties of the metallic alloy.

The results obtained from the three-point bending test, till 1 mm deformation of the immersed NiTi arch wires does not indicate an alteration of forces intensity. On the contrary, the tendency is to increase the values of the forces. This aspect may be explained by corrosion phenomena induced by solutions with a consecutive alteration of the surface structure and an increase of the frictional force at the bracket-arch slot interface. Kusy [37] explained the complexity of the phenomena that should be taken into the calculation of the friction force developed at the interface between the bracket and the arch wire, factors such as partial overlapping areas and surface defects which significantly change the value of the frictional forces [37] and the force necessary to overcome the supplementary friction force explain the growth of these parameters.

The only arch that seems to be affected by fluoride in the sense of diminishing the forces is the 0.016x0.022 NiTi arch wire, but only to a bending up to 4 mm, the deactivation force at 2 mm reducing from 5.11 N to 3.6 N (*p=*0.001). A possible explanation is in the increased absorption of hydrogen in the area of contact with the fluoride.

The testing of the bending properties of the immersed arch wires into coke has not been reported in the previous studies, the comparison of the obtained results with those from the literature not being possible.

The SS immersed arch wires, both the round and the rectangular ones, showed the same tendency of increasing the activation and deactivation forces. The phenomenon of friction growth explains these increases, especially since many authors [41, 46-48] have noticed signs of corrosion on the surface of the immersed arch wires into various solutions.

β-Ti arch wires seem to be the most affected by the fluoride and coke immersion. Thus, the activation force to 2 and respectively 4 mm has grown, while the deactivation one significantly decreased in the case of the immersed into coke arch wires, which reached only 0.14 N to 2 mm. These results are according to those obtained by Walker [16]. According to his study, after the immersion into fluorinated solutions, the deactivation parameters (the elastic modulus and the breaking resistance to deactivation) decreased for the β-Ti arch wires. The explanation may lie in the dissolution of the passive oxide film of the arch wires having Ti in their composition under the action of the acidic solutions of fluoride.

The mechanical properties of β-Ti shall be modified due to hydrogen absorption after the degradation of the protective layer [18]. These reactions explain the degradation of the arch wires immersed into fluorinated acidic solutions (APF), where the hydrofluoric acid is present, but not in the case of immersion into neutral solutions [16]. The immersion solution we have used, although it does not contain H3PO4, has a pH of 4, so it is acid. Watanabe *et al*. [17] did not observe changes in the roughness of the surface of the β-Ti arch wires immersed into neutral solutions, but for those immersed into APF for 24 hours it statistically showed a significant increase in roughness.

After the three-point bending test of the immersed arch wires aesthetically covered the value of the deactivation forces at 2 mm remained 0, both for those immersed into coke as well as for those immersed into fluoride. Bandeira's study [49] on the frictional forces of the aesthetic arch wires immersed into fluoride for 30 days showed a significant increase in the friction of the immersed arch wires, growth explained by the increase of the roughening the surface of these arch wires due to the acid attack. However, the immersion time in the case of our study was reduced. It was 7 days unlike the 30 days from Bandeira’s study [49].

The study of dental and orthodontic materials paid a particular attention to the evaluation of the properties of the new arch wires, while the changes that occurred after the use of the arch wires in an intra-oral environment have been less investigated [34,38,42,50]. One of the few studies like this is that of Wickelhaus [50], about the surface roughness and the friction of the 0.016x0.022 inch, intra-orally used NiTi arch wires. The SS arch wires have been investigated by Marques [40], in terms of the surface roughness and friction. He observed a significant increase in the two parameters after the exposure for 8 weeks in an intra-oral environment.

The round NiTi intra-orally used arch wires were divided into two categories, depending on the time of the intra-oral usage. Thus, the average values of the flow resistance, of the tensile breaking strength and of the elasticity modulus, even if they were lower than those of the new arches, there were no significant differences in statistical terms, regardless of the time of usage. This suggests that the use of round NiTi arch wires for a long time in the intra-oral medium does not determine a significant alteration of these three parameters.

The most affected arch wires seem to be the NiTi ones with the section of 0.016x0.022 used more than 6 weeks in an intra-oral environment. In their case, the values of these three parameters significantly decreased (p<0.05). The results of our study are according with those of Zinelis *et al*. [42]. The authors have tested the fracture resistance of the new arch wires and of those recovered by repeated application of the bending forces until their effective fracturing. They concluded that the tensile strength drops to the rectangular or square arch wires in comparison with the round NiTi arch wires. Also, the breaking strength is higher when the new arch wires are compared to those intra-orally used [42].

In contradistinction to NiTi arch wires, the round SS ones are more affected after the intra-oral usage. Thus, the significant decrease of the flow resistance, of the tensile strength and of the elastic modulus of 0.016 inch SS arch wire has occurred whatever the time of the intra-oral usage was. As in the literature we found no studies to confirm or negate our results, we believe that the possible explanation for these decreased values could be the permanent (plastic) deformations produced during the ligatures of the arch wires were made, but especially when exercising the chewing functions. These factors may cause deformation of the rounds section arch wires and small dimensions, more than in the case of the bigger ones with a rectangular section. The macroscopic analysis of SS round arch wires recovered from patients confirms the presence of these plastic deformations.

The tensile testing of the 0.016 inch esthetic NiTi arch wires recovered could not be achieved. We were unable to determine the exact amount of tensile strength due to technical difficulties, these arch wires sliding from fixing bracket. Unlike the new arch wires where the distal portion attached to the clamping jaws of the test machine was not covered by the aesthetic coating, to those placed into the oral cavity this portion was cut out. Thus, during the tensile test Teflon coating broke away from the metallic surface.

The bending test of the orthodontic arch wires with the activation and deactivation establishment of the forces are imposed by the last ISO specifications and because the deactivation forces are responsible for the tooth movement, they are of a major clinical importance.

In the case of NiTi round section arch wires, the values ​​of the deactivation forces to 2 mm have been significantly reduced. Eliades [39] said that after the intra-oral exposure the surface topography of these arch wires is significantly altered, with possible implications on their mechanical properties. Thus, by increasing the surface roughness determined by an appliance, the frictional force at the bracket- slot interface may increase [34, 36]. After the deformation, the restoring force must overcome the additional frictional resistance from the slot. This explanation is valid for the rectangular arch wires too, especially since the contact area between the arch and the slot and, implicitly, the friction surface are higher.

Significantly reduced values of the deactivation forces were obtained for the SS arch wires. Both in the case of the round and rectangular arch wires, the deactivation forces at 0.5 mm and 2 mm were equal to 0. While for the SS arch wires the deactivation force value 0 to 2 mm can be explained by the occurrence of permanent deformations. These distortions do not occur when bending the SS arches to 1 mm only [9]. The increase of the surface roughness and of the friction at the slot-arch interface is another factor that may reduce the average values of force deactivation. Marques' study [40] confirms this hypothesis, the author observing a 20.8% increase of the SS arch friction after 8 weeks of use in vivo. Also, some other studies [36,40,51,52] confirm the correlation between the increases of the roughness due to intra-oral corrosion of the arch wires based on an SS alloy.

Numerous studies [35,38,43] have confirmed that the aesthetic coated arch wires exposed in an intra-oral environment suffer major deteriorations both of the mechanical properties and of the aesthetic ones as a result of the accentuated deterioration of the coating. The results of our study are according to the literature, the deactivation forces being zero like in the case of the arch wires tested by Elavyan [35]. The same author has obtained higher values of the activation forces for the recovered arch wires in comparison with the new ones, values that may be explained by the increased friction.

The analysis of the surface characteristics of the orthodontic arch wires by means of optical and electronic microscopy revealed many differences, due to the alloy used in manufacturing, to the surface treatment, to the manufacturing process and to the environmental complexity in vitro or in vivo where these arch wires are used.

In this study we observed many defects on the surface of the new SS round and rectangular arch wires. These defects are presented in various forms and have a varied arrangement but most of them are parallel to the long axis of the arch wires. Such defects as well as their correlation between their presence and the degradation of the arch wires were also highlighted in the study by Paul et al. [51].

In the case of the SS arch wires intra-orally used, we could detect many changes of the surface topography. Thus, on the SEM images, both signs of chemical degradation by corrosion with the occurrence of corrosion signs in the form of large circular areas which are joined together, as well as degradation signs through mechanical deformation in the form of scratches, especially at the bracket -arch interface can be observed. In contrast to other studies [39,41], in this study, large deposits of organic material on the surface of the intra-orally used arch wires were not observed, even if the extraction protocol of these arch wires included the washing with distilled water only but not the cleaning with acid and alkaline solutions.

Previous study [16] on the effect of the fluorinated solutions on the surface of the SS arch wires showed that after immersion, both the initial surface processed as well as the associated semicircular characteristics have become more evident. A possible explanation of these changes may be the destruction of protective oxide coating layer. However, to confirm the presence of corrosion products associated with the fluoride some X-ray diffraction spectroscopy studies are needed [16].

After the immersion into a fluorinated solution, we detected similar changes to those in Walker’s study [16]. The initial defects deepened and corrosion appeared in the form of stains.

We observed a greater affectation of the arch wires immersed into the fluorinated solution compared with those immersed into coke. Thus, a stretching of the surface and a deepening of the cracks on the surface of the arch wires could be highlighted. Also, on the MO images, the changes in the color of the NiTi arch wires immersed into fluoride were highlighted, changes visible even with a human’s eye. Kaneko's study [18] has detected significant changes in the surface topography of the immersed arch wires with the increasing of the roughness through corrosion of NiTi arch wires, the occurrence of the uniform corrosion signs for the β-Ti arch wires and signs of corrosion unevenly distributed on the surface of the SS arch wires.

The effect of carbonated drinks on the enamel had been evaluated in several studies [31,32], but their effect on orthodontic arch wires had been evaluated in one study only by Abalos [33]. The results of that study show that carbonated drinks with a low pH have corrosive effects to the surface of NiTi arch wires. The results of our study are according with those of Abalos [33], about the NiTi arch wires affected by coke.

The investigated NiTi intra-orally used arch wires revealed clear signs of uniform corrosion with the presence on small areas of organic deposits. The electron-microscopic investigations of the arch wires intra-orally used conducted by Eliades [39] have shown that the formation of a film of organic substances on the surface of the NiTi arch wires may cause an increased roughness of the surface and implicitly affect the sliding mechanics.

The microscopic analysis of the intra-orally used arch wires was conducted in several studies [35,44]. These authors observed a loss of the aesthetic cover directly proportional to the time of the intra-oral usage. Thus, Elavyan [35], observed the damage to the coating with its loss in a proportion of 26% after a period of usage of 33 days. Our results are according to those of Elavyan [35], the loss of the coating being directly proportional to the exposure time, although a significant damage was observed even when using the arch wires for less than a month in an intra-oral environment.

5. CONCLUSIONS

a. Both the mechanical and surface properties are modified by the intra-oral usage of the arch wires. These changes are more evident in the case of the arch wires with an increased elastic modulus, most likely as a result of the plastic deformations that occurred due to their prolonged usage.

b. The change of the surface topography of the orthodontic arch wires may determine changes of the bending characteristics by increasing the roughness of the surface.

c. The immersion into fluoride particularly affects the arch wires containing Ti. Additional research of scanning differential calorimetry is needed of to determine the complex mechanism by which the fluoride interferes with the transformations at the inter-atomic level.

d. The low efficiency of the NiTi aesthetic covered arch wires observed during their intra-oral usage has been confirmed by all the mechanical tests conducted.

e. The existence of a correlation between the mechanical and surface properties of the intra-orally used arch wire is obvious in the sense of modifying the frictional characteristics to the slot- arch interface.

f. To increase the effectiveness of the arch wires during the fixed orthodontic treatment it is recommended for the clinicians to monitor the dietary and hygiene habits of patients, as well as to shorten the time of the usage of the arch wires in an intra-oral environment by changing them with new arch wires.

REFERENCES

1. Kusy RP. A review of contemporary arch wires: Their properties and characteristics. *Angle Orthod* 1997; 67(3): 197-208.
2. Miura F, Mogi M, Ohura Y and Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. *Am J Orthod Dentofac Orthop* 1986; 90(1): 1–10.
3. Oltjen JM, Duncanson MG Jr, Ghosh J, Nanda RS and Currier GF. Stiffness-deflection behavior of selected orthodontic wires. *Angle Orthod* 1997; 67: 209–218.
4. Johnson E and Lee RS. Relative stiffness of orthodontic wires. *J Clin Orthod* 1989; 23: 353–363.
5. Kusy RP and Dilley GJ. Elastic modulus of a triple-stranded stainless steel arch-wire via three and four point bending. *J Dent Res* 1984; 63: 1232–1240.
6. Kusy RP and Stush AM. Geometric and material parameters of nickel-titanium and a beta-titanium orthodontic arch wire Alloy. *Dent Mater* 1987; 3: 207–217.
7. Goldberg AJ and Burstone CJ. Status report on beta-titanium orthodontic wires. Council on dental materials, instruments and equipment. *J Am Dent Assoc* 1982; 105: 684–685.
8. Garrec P and Jordan L. Stiffness in bending of a super-elastic Ni-Ti orthodontic wire as a function of cross sectional dimension. *Angle Orthod* 2004; 74: 691-696.
9. Krishnan V and Kumar KJ. Mechanical properties and surface characteristics of three arch wire alloys. *Angle Orthod* 2004; 74: 825–831.
10. Nakano H, Satoh K, Norris R, Jin T, Kamegai T, Ishikawa F and Katsura H. Mechanical properties of several nickel-titanium alloy wires in three-point bending test. *Am J Orthod Dentofac Orthop* 1999; 115: 390–395.
11. Parvizi F and Rock WP. The load-deflection characteristics of thermally activated orthodontic arch wires. *Eur J Orthodont* 2003; 25: 417–421.
12. Wilkinson PD, Dysart PS, Hood JA and Herbison GP. Load deflection characteristics of super-elastic nickel-titanium orthodontic wires. *Am J Orthod Dentofac Orthop* 2002; 121: 483–495.
13. Hammad SM, Al-Wakeel E and Gad E. Mechanical properties and surface characterization of translucent composite wire following topical fluoride treatment. *Angle Orthod* 2012; 82 (1): 8-13.
14. Graber TM and Vanarsdall RL Jr. *Orthodontics. Current principles and techniques*, 2nd edition, Mosby, Year Book Inc., St Louis **University of Michigan;** 1994**: 233-238.**
15. Proffit WR and Fields HW. *Contemporary orthodontics*. Mosby, St. Louis, Mo, USA, 3rd edition; 2000: 405-410.
16. Walker M, Ries D, Kula K, Ellis M, Fricke B. Mechanical properties and surface characterization of beta titanium and stainless steel orthodontic wire following topical fluoride treatment. Angle Orthod 2007; 77(2): 342-348.
17. Watanabe I, Watanabe E. Surface changes Induced by Fluoride Prophylactic Agents on Titanium-Based Orthodontic Wires. Am J Orthod Dentofacial Orthop 2003; 123: 653–656.
18. Kaneko K, Yokoyama K, Moriyama K, Asaoka K, Sakai J. Degradation in performance of orthodontic wires caused by hydrogen absorption during short term immersion in 2.0% acidulated phosphate fluoride solution. Angle Orthod 2004; 74(4): 487-495.
19. Nakagawa M, Matsuya S, Udoh K. Corrosion behavior of pure titanium and titanium alloys in fluoride - containing solutions. Dent Mater J 2001; 20: 305–314.
20. Nakagawa M, Matsuya S, Udoh K. Effects of fluoride and dissolved oxygen concentrations on the corrosion behavior of pure titanium and titanium alloys. Dent Mater J 2002; 21: 83–92.
21. Huang H-H. Effects of fuoride concentration and elastic tensile strain on the corrosion resistance of commercially pure titanium. Biomaterials 2002; 23: 59–63.
22. Huang H-H. Electrochemical impedance spectroscopy study of strained titanium in fluoride media. Elecrochim Acta 2002; 47: 2311–2318.
23. Schiff N, Grosgogeat B, Lissac M, Dalard F. Inﬂuence of fluoride content and pH on the corrosion resistance of titanium and its alloys. Biomaterials 2002; 23: 1995–2002.
24. Yokoyama K, Kaneko K, Moriyama K, Asaoka K, Sakai J, Nagumo M. Hydrogen embitterment of Ni-Ti super-elastic alloy in fluoride solution. J Biomed Mater Res 2003; 65: 182–187.
25. Kaneko K, Yokoyama K, Moriyama K, Asaoka K, Sakai J, Nagumo M. Delayed fracture of beta titanium orthodontic wire in fuoride aqueous solutions. Biomaterials 2003; 24: 2113–2120.
26. Takemoto M, Shonohara T, Shirai M, Shinogaya T. External stress corrosion cracking (ESCC) of austenitic stainless steel. Mater Perf 1985; 24: 26–32.
27. Zucchi F, Trabanelli G, Demertzis G. The inter-granular stress corrosion cracking of a sensitized AISI 304 in NaF and NaCl solutions. Corros Sci 1988; 28: 69–79.
28. Shibata T, Haruna T, Oki T. Initiation and growth of inter-granular stress corrosion cracks for sensitized 304 stainless steel depending on NaF concentration of aqueous solution. Tetus-to-Hagane 1993; 79: 721–725.
29. Yamazaki O. Effect of fluoride ion on the crevice corrosion for type 304 stainless steel in neutral NaCl solution. Zairyo-to-Kank- yo 1996; 45: 365–359.
30. Bastidas JM, Fosca C, Chico B, Otero E. Weight loss and electrochemical results for two super-austenitic stainless steels in chloride-fluoride mixtures. Corros Sci 1996; 38: 559–563.
31. Van Eygen I, Vannet BV, Wehrbein H. Influence of a soft drink with low pH on enamel surfaces: an in vitro study. Am J Orthod Dentofacial Orthop 2005, 128(3): 372–377.
32. Von Fraunhofer JA, Rogers MM. Dissolution of dental enamel in soft drinks, Gen Dent 2004; 52: 308–312.
33. Abalos C, Paul A, Mendoza A, Solano E, Palazon C, Gil FJ. Influence of soft drinks with low ph on different NiTi orthodontic arch-wire surface patterns. Published online: J of Mat Eng and Perf 2012
34. Eliades T, Bourauel C. Intraoral aging of orthodontic materials: the picture we miss and its clinical relevance. Am J Orthod Dentofacial Orthop 2006; 127(4):403-412.
35. Elayyan F, Silikas N, Bearn D. Mechanical properties of coated super-elastic arch wires in conventional and self-ligating orthodontic brackets. Am J Orthod Dentofacial Orthop 2010; 137:213–217.
36. Reznikov N, Zion G, Barkana I, Abed Y, Redlich M. Influence of friction resistance on expression of super-elastic properties of initial NiTi wires in “reduced friction” and conventional bracket systems. J Dent Biomech 2010; 1: 25-30
37. Kusy RP, Whitley JQ, “Friction between different wire-bracket configurations and materials,” Seminars in Orthodontics 1997; 3 (3): 166–177.
38. Eliades T, Athanasiou A. In vivo aging of orthodontic alloys: implications for corrosion potential, nickel release, and biocompatibility. Angle Orthod 2002; 72: 222-237.
39. Eliades T, Eliades G, Athanasiou AE, Bradley TG. Surface characterization of retrieved NiTi orthodontic arch wires. Eur J Orthod 2000; 22 (3): 317-326.
40. Marques ISV, Araújo AM, Gurgel JA, Normando D. Debris, roughness and friction of stainless steel arch wires following clinical use. Angle Orthod 2010; 80(3): 521-527.
41. Daems J, Celis JP, Willems G. Morphological characterization of as-received and in vivo orthodontic stainless steel arch wires. Eur J Orthodont 2009, 31(3): 260-265.
42. Zinelis S, Eliades T, Pandis N, Eliades G, Bourauel C. Why do nickel titanium arch wires fracture intraorally fractographic analysis and failure mechanism of in-vivo fractured wires. Am J Orthod Dentofacial Orthop 2007; 132(1): 84–89.
43. da Silva DL, Mattos CT, de Araújo MVA, de Oliveira Ruellas AC. Color sStability and fluorescence of different orthodontic esthetic arch wires. Angle Orthod 2013; 83(1): 127-132.
44. Trethewey KR, Chamberlain J. Crevice and pitting corrosion. Corrosion for Students of Science and Engineering. New York, NY: John Wiley & Sons Inc; 1988: 134–149.
45. Pernier C, Grosgogeat B, Ponsonnet et al. Influence of autoclave sterilization on the surface parameters and mechanical properties of six orthodontic wires. Eur J Orthod 2005; 27(1): 72-81.
46. Articolo LC, Kusy K, Saunders CR, Kusy RP. Influence of ceramic and stainless steel brackets on the notching of arch wires during clinical treatment. Eur J Orthod 2000, 22(4): 409-425.
47. Acharya A, Jayade VP. Metallurgical properties of stainless steel orthodontic arch wires: a comparative study. Trends Biomat 2005; 18(2): 125-136.
48. Kim H, Johnson JW. Corrosion of stainless steel, nickel-titanium, coated nickel-titanium and titanium orthodontic wires. Angle Orthod 1999; 69: 39–44.
49. Bandeira AMB, dos Santos MPA, Pulitini G, Elias CN, da Costa MF. Influence of thermal or chemical degradation on the frictional force of an experimental coated NiTi wire. Angle Orthod 2011; 81(3): 484-489.
50. Wichelhaus A, Geserick M, Hibst R, Sander FG. The effect of surface treatment and clinical use on friction in NiTi orthodontic wires. Dent Mater 2005; 21: 938–945.
51. Paul A, Abalos C, Mendoza A, Solano E, Gil FG. Relationship between the surface defects and the manufacturing process of orthodontic Ni-Ti arch wires. Mater Lett 2011; 65 (23–24): 3358–3361.
52. Drescher D, Bourauel C, Schumacher H. Frictional forces between bracket and arch wire. Am J Orthod Dentofacial Orthop, 1989; 96 (5): 397–404.

LEGEND:

**Fig. 1**. A comparative diagram of the bending test at 4 mm of Phys - NiTi 0016 for new and immersed arch wires

Fig. 2. Bending testing for the new and immersed arch wires - 1 mm NiTi 0.016x0.022

Fig. 3. A comparative diagram of the bending tests at 1 mm of the new and immersed SS 0.016 arch wires

Fig. 4. A comparative diagram of the bending tests at 1 mm of the SS 0.016x0.022 new and immersed arch wires

Fig. 5. A comparative diagram of bending NiTi and SS rectangular arch wires

Fig. 6. Scanning electron microscopy (x300) (a) and optical microscopy (b) images of NiTi new, as-received arch wires

Fig. 7. (a) MO image of the round NiTi arch wire immersed into topical fluoride solution, (b) SEM image of the same arch wire x3000, (c) SEM image of the intra-orally used NiTi arch wire x 300

Fig. 8.(a) SEM image of the IO SS rectangular arch wire; (b) Friction corrosion on the surface of the SS rectangular arch wire, IO; (c) MO image of SS Used intra-orally used round arch-wire

Fig. 9. SEM images of the -Ti arch-wires: (a) new, (b) immersed in soft drink, (c) topical fluoride immersed into solution, (d) intra-orally used

Fig. 10. SEM images of the aesthetic NiTi arch-wires: (a) new, (b) immersed into coke, (c) immersed into topical fluoride solution

Fig. 11. SEM image of an aesthetic NiTi arch wire intra-orally used