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Analysis of the Hardness, Nano Indentation and Nano Roughness of NiTi Orthodontic Arch wires

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Abstract **Original Research Article**

Objective: The aim was to observe the modification of NiTi arch wires mechanical characteristics before and after their use and to highlight that when shape memory and super elasticity are stressed, hardness and roughness are also altered. ***Materials and methods***: Samples of used and new 0.016-0.022- and 0.016-inch archwires made by American Orthodontics (AO), AZDent and Ortho Classic (OC) were retrieved from 192 patients. They were analyzed using an Atomic Force Microscope, a hardness tester and SEM. The arches were classified into various categories: the qualitative factors that include manufacturers, type, usage, age, gender, size and location. The quantitative factors include roughness (nm) and hardness (Vickers). The analysis was divided into three parts, comparison of new arches for all three companies, comparison of used arches between all three and comparison between new and used arches company by company. ***Results:*** As expected, the acquired results revealed a decrease in the hardness value (ΔHV~50 Vickers) of the retrieved samples after 4–6-week oral installation compared to the control samples, as well as increased surface roughness and porosity. AZDent brand bows have the smallest drop in hardness. The AO brand arches proved to be the roughest while those manufactured by AZDent were the smoothest. It should also be noted that 0.016-0.022 arches showed the most degradation. ***Conclusion:*** We was able to demonstrate that the mechanical properties of NiTi arches (shape memory and super-elasticity) appear to differ significantly before and after intra-oral usage. That mean the old arch wires have fewer mechanical properties than the new one and, in this situation, we need to find a solution to avoid this problem.

Keywords: Hardness, archwires, roughness, AFM, SEM.

INTRODUCTION

The surface qualities of orthodontic archwires, such as topography and hardness, are critical factors of the efficiency and efficacy of archwire-guided tooth movement. They also have an impact on the corrosion resistance and appearance of orthodontic appliances.

Additional studies in this domain have been conducted; According to Krishnan *et al.*, study, when compared to the control samples, all surface-modified NiTi conventional groups show a significant change in surface roughness [1]. Scanning electron microscopy (SEM) exposes and demonstrates that NiTi archwires have a rougher surface structure than stainless steel archwires. However, due to the limited immersion periods, no corrosion was observed (hours rather than days or weeks) [2]. Temperature sensitivity variations for super-elastic NiTi wires between retrieved and control archwires are significant and, as a result, changes in oral temperature may cause stress degradation in NiTi wires during orthodontic treatment [3].

The aim of this study is to corroborate these results and show that mechanical qualities such as hardness and roughness are not the same before and after use in the mouth. Furthermore, the correlation study and two-way analysis of variance (ANOVA) confirm that when features like shape memory and super elasticity change, other properties like hardness and roughness change as well. Significant variations in the archwires before and after use in the mouth were discovered in these three examinations over a 4-6-week period. The hardness process makes use of specialized gear and software that has substantially improved the testing condition and results[4] Roughness is an important parameter in this testing because it gives broad-based information about the surface status of the wire material. This is useful to locate a smooth surface to, for instance, measure the quality of sliding dental movements in the wire. Rough surfaces are generally affected more quickly than smoother surfaces, and they are also more prone to developing corrosion and cracks.

MATERIALS AND METHODS

For all categories, all archwires were examined using statistical analysis.

Hardness Test

This test, based on Vickers measure, with three indentations for each wire and patient. The machine employed was a Buehler USA (HMV-G 21 series-MICRO HARDNESS VICKERS TESTER). Indentations were done at nanometer diameter and depth. Archwire hardness should be measured on new wires and after use in the oral cavity to see whether there are any variations. The testing process makes use of specialized gear and software that has substantially improved the testing condition and results [4].

Each wire was cut to a length of 20 mm for testing, with three locations along its length assessed for hardness. After utilizing a diamond disc to make a spot to accept the wire, each wire sample had a circular piece of Teflon (20 mm in diameter and 2 mm thick) glued to the surface. The bonding resulted in the formation of an acryl resin. As previously stated, the test was performed in three places for each sample (i.e., three indentations per wire) to limit the chance of error.

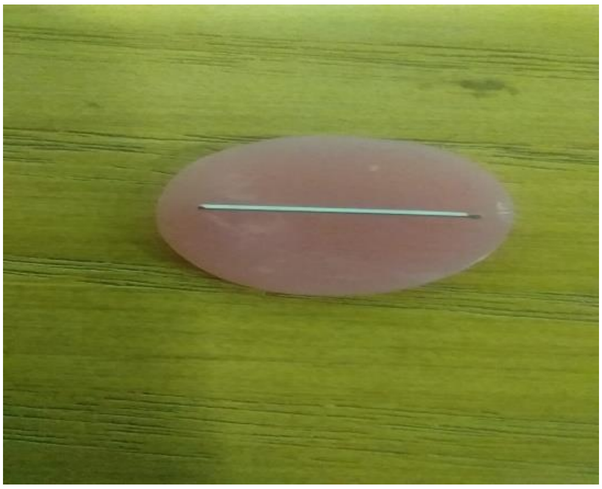


Fig 1: This is one of the samples of hardness testing of arch wire NiTi (testing by hazardous of affected and non-affected zones)

Roughness test

A roughness tester machine is used to identify the surface texture or surface roughness of the wire. We determined the roughness depth (Rz) as well as the mean roughness value (Ra) in micrometers or microns (µm) [5].

For each archwire, we cut 1-2 mm from the end and put it in the roughness machine using a ceramic probe. For our quantitative measure, we used the roughness index (RA) as a reference [6].

SEM (Surface Electronic Microscope)

Sample we used the same wire but only 1 mm length piece of wire as the profilometry (roughness test) samples, which we previously washed with distilled water to eliminate contaminants. All different types of samples were used. There is a special place for fixation of the samples inside the machine, and also, we have chosen the samples from every wire used and new by hazardous with a magnification of 1500.

Description of the three companies' archwires

Three manufacturers of orthodontic archwires are used in this study: American Orthodontics (AO), Ortho Classic (OC) and AZ Dent (AZD). Tables 1-6 below present the various features of these companies' archwires, categorized by characteristics and parameters. All three companies had comparable category divisions. All orthodontic archwires were subjected to hardness, roughness, and SEM examinations in order to discover the relationship between the tests.

Table 1: AO selection of new archwires

American Ortho				
New				
0.016 inch		**0.016-0,022 inch**		
Upper	Lower	Upper	Lower	
4	4	4	4	**Total :16**

Table 2: AO selection of used archwires

	American Ortho				
	Used				
	(0.016 inch;0,016-0,022 inch)				
	Upper		**Lower**		
	Female	**Male**	**Female**	**Male**	
Teenager	**(3;3)**	**(3;4)**	**(3;3)**	**(4;3)**	
Adult	**(3;3)**	**(3;3)**	**(3;4)**	**(3;3)**	**Total :51**

Table 3: OC selection of new archwires

Ortho Classic				
NEW				
0.016 inch		**0.016-0.022 inch**		
Upper	Lower	Upper	Lower	
2	2	2	2	**Total :8**

Table 4: OC selection of used archwires

	Ortho Classic				
	Used				
	(0.016 inch; 0.016-0.022 inch)				
	Upper		Lower		
	Female	Male	Female	Male	
Teenager	(3;3)	(4;2)	(2;2)	(3;3)	
Adult	(3;3)	(3;3)	(4;3)	(4;3)	**Total :48**

Table 5: AZ Dent selection of new archwires

AZ Dent				
NEW				
0.016 inch		**0.016-0.022 inch**		
Upper	Lower	Upper	Lower	
3	3	3	3	**Total :12**

Table 6: AZ Dent selection of used archwires

	AZ Dent				
	Used				
	(0.016 inch; 0.016-0.022 inch)				
	Upper		Lower		
	Female	Male	Female	Male	
Teenager	(2;3)	(3;4)	(4;3)	(4;3)	
Adult	(4;3)	(4;3)	(5;4)	(4;3)	**Total :56**

Statistical study using two-way analysis of variance technique

XLSTAT was used to conduct the analysis (Microsoft Excel 2016). The inter-group comparison was done using ANOVA, and the POST HOC analysis was done using the Tukey Criterion. The research was split into three sections. The first portion compared the three manufacturers' new arches (AO, OC, and AZD), the second part compared the new and used arches company by company, and the third part compared the used arches among the three manufacturers.

The arches were categorized into several categories that included the ANOVA's qualitative variables: manufacturer (AO, OC, and AZD), type (upper, lower), use (new, used), age (teenager, adult), gender (male, female), size (0.016inch round, 0.01616-0.022 inch rectangular), and position (PG, A, PD). The quantitative factors include roughness (nm), and hardness (Vickers).

The SEM results are given as a modal variable (Acceptable, Poor, and Very Bad) and are used as a control descriptive variable to analyze the correlation with quantitative factors. The presence of pathology without differentiation in patients (yes, no) and their periodontal status (acceptable, poor, and very bad) allow us to investigate any influence of these two variables on the quantitative variables.

The correlation investigation was conducted according to Pearson's criterion. The alpha significance level was set at 0.05 (0.05 = significant test, 0.0001 = extremely significant test). The error bars on the histograms represent the standard error for each group.

RESULTS

Hardness Test Results

Figures 0-4 showed graphical comparison between hardness and many parameters such as: Position (Figure 1), Dimension (Figure 2), Type (Figure 3), Gender (Figure 4), and Age (Figure 5).

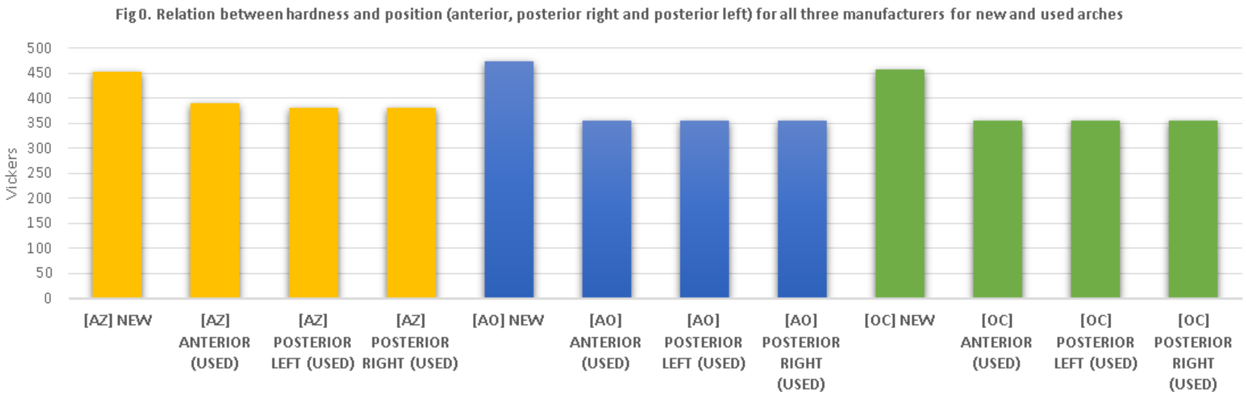


Fig 2: Relation between hardness and position for all three manufactures for used and new arches

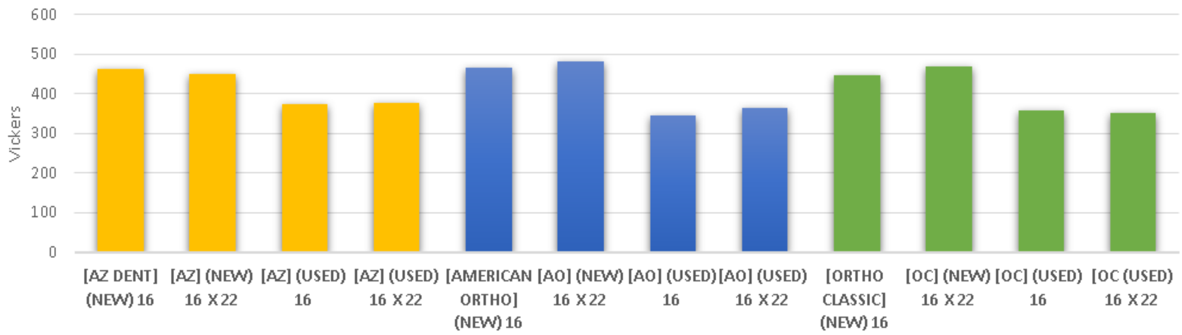


Fig 3: Hardness vs dimension comparison of new and used archwires for all three manufactures

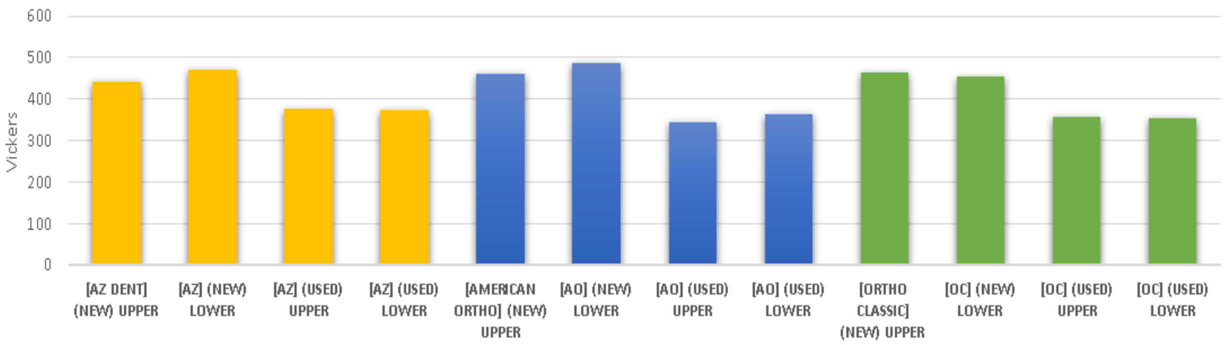


Fig 4: Relation between hardness and types of the wires for all three manufactures

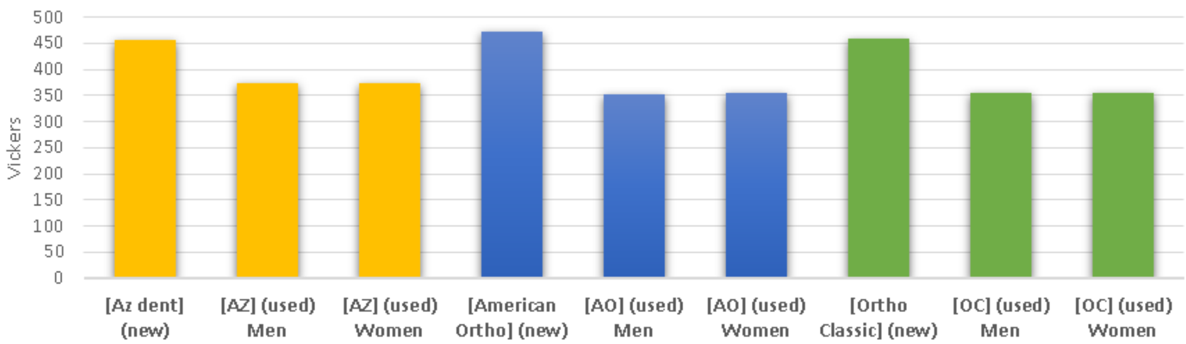


Fig 5: Relation between hardness and different genders for all three manufactures

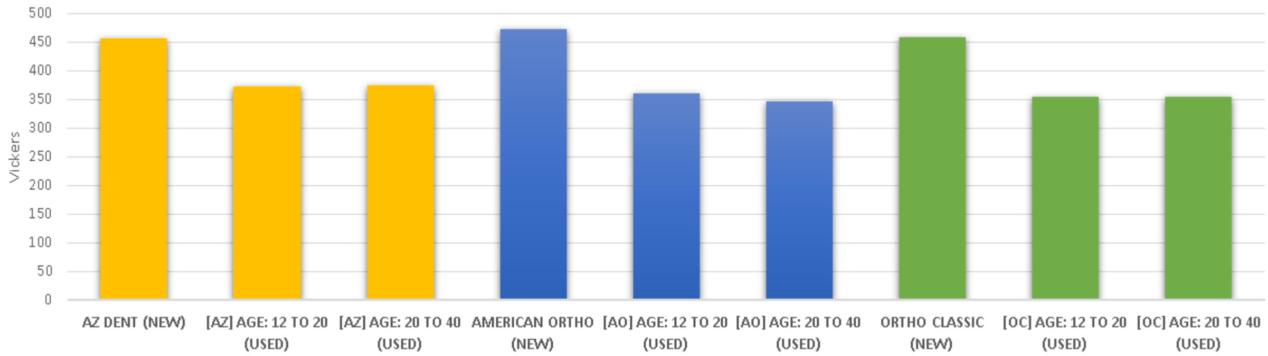


Figure 6: Relation between hardness and age for all three manufactures

3.2 Roughness Test Results

The roughness test results are similar to the hardness testing results, in that all the new archwires presented less roughness on their surface compared to the used wires. The main parameters applied in the roughness test are dimension (round vs rectangular), type, sex age and position (Figures 6 to 10).

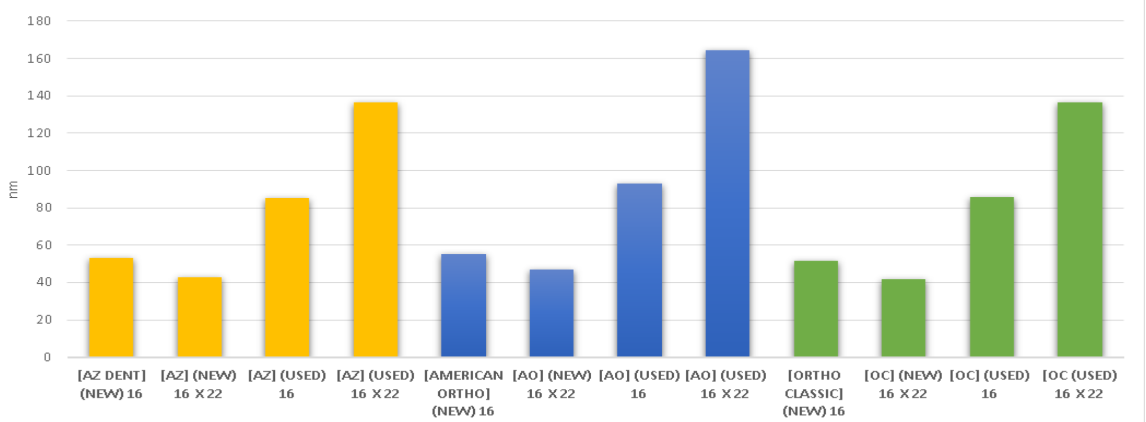


Figure 7: Roughness vs Dimension comparison of new and used archwires for all three manufactures

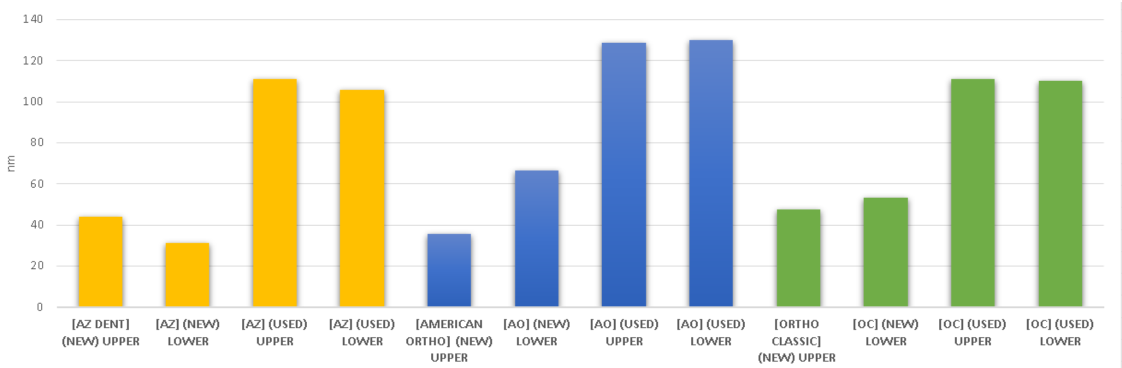


Figure 8: Relation between roughness and type of the wire for all three manufacturers

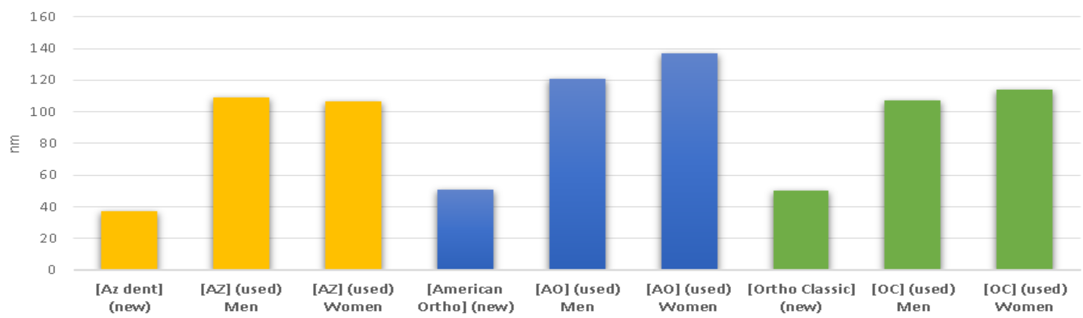


Figure 9: Relation between roughness and gender for all three manufacturers

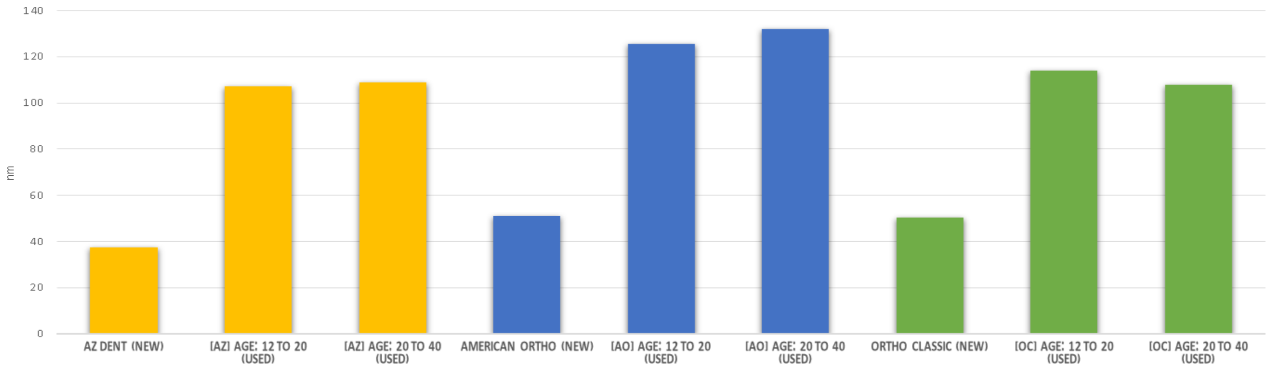


Figure 10: Relation between roughness and age for all three manufacturers

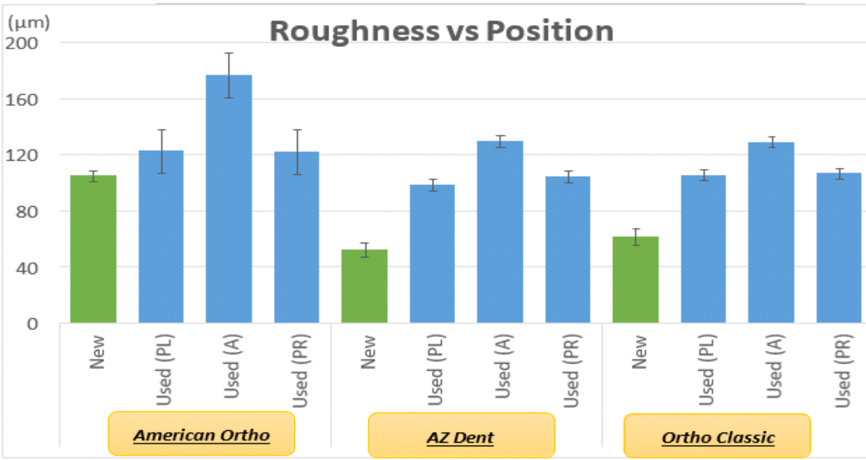


Figure 11: Relation between roughness and position (anterior, posterior right and posterior left) for all three manufacturers for new and used arches

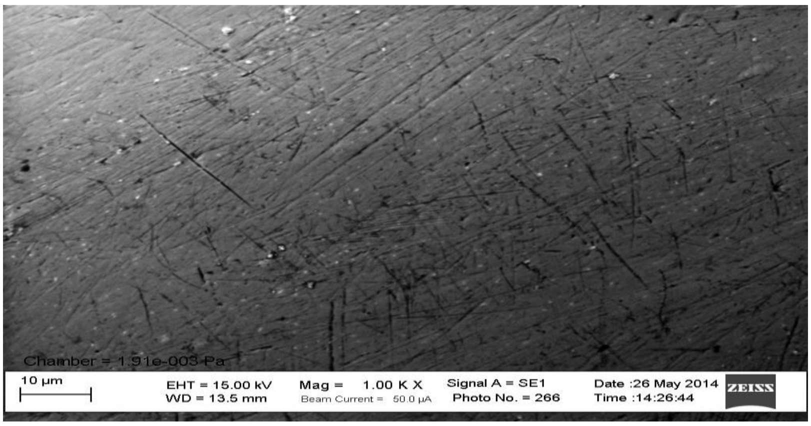
In reviewing the results for teenagers and adults, we can see there are no major differences between the used archwires. However, regarding the position of the wire in the mouth, the anterior position appears to be more affected for all three companies, with AO being the most affected (Figs 9 and 10).

SEM Test Results

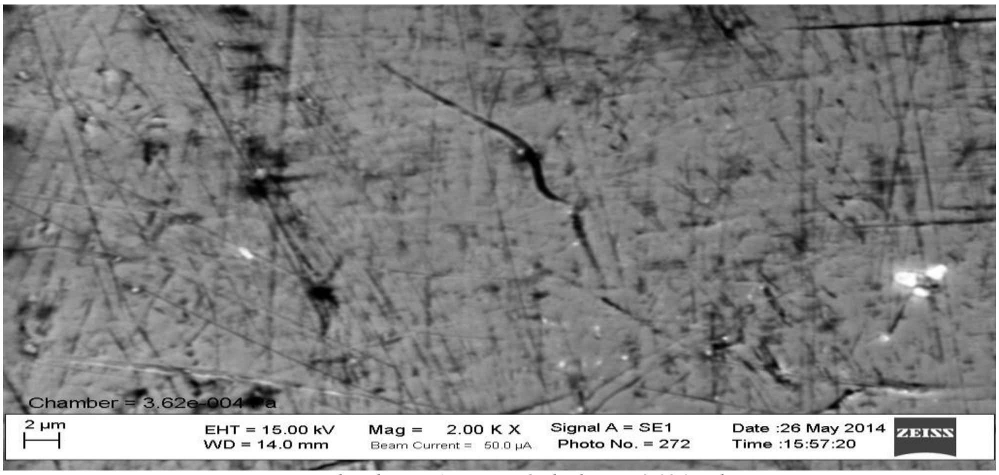
The qualitative findings of the SEM test provide information about the condition of the surface of archwires at magnifications ranging from 500 to 2000. As seen in both the hardness and roughness tests, all of the used samples showed more porosity, striations, and general surface deterioration than the other two manufacturers. The AZ Dent firm had the worst archwire samples, followed by Ortho Classic. American Orthodontics produced the best archwires. B: Used arch wire American Orthodontics 0.106 inch

depicted the changes between American Orthodontic Company's new and used 0.016-0.022- and 0.016-inch dimensions.

American Orthodontic Company's new and used 0.016-0.022 and 0.016 inch dimensions.



A: New American Orthodontics 0.016-inch archwire



B: Used arch wire American Orthodontics 0.106 inch

Figure 12: Comparison between new and used archwire in SEM

The difference between new archwires manufactured by (A) American Orthodontics and used archwires is depicted in this figure (B). The used archwires' striations, porosity, and surface deterioration are clearly visible. Archwires from the three companies mentioned were tested in the same way, and the results revealed that all of the used wires were rougher than the new archwires. The AZ Dent archwires were found to be the roughest of the three manufacturing companies in terms of quality.

DISCUSSION

In general, the results go in the same direction, meaning that all of the used archwire samples have a lower rate of hardness, greater roughness, and a larger area of SEM observed deterioration compared to the new archwires. These results are identical to those of Pop and Dudescu [7], who demonstrated that the elastic modulus test for NiTi 0.016 inch and NiTi 0.016 x 0.022-inch archwires show lower thresholds for recovered arches (intra-oral use of 4-6 weeks) compared to the new ones. In the case of 0.016-inch NiTi arches, Eberle and All note a decrease in the value of the three parameters (tensile test, strength, and modulus of elasticity); additionally, they found that the super-elasticity decreases automatically, though statistically insignificantly. The same observation also applies to the intra-oral use of 0.016 x 0.022 inch NiTi arches. This results in a decrease in the values of the three parameters previously observed, especially when using arches for longer than 6 weeks7, Furthermore, when the modulus of elasticity decreases, the other properties of hardness, roughness and elasticity also degraded.

Concerning the exposure of arches in the intra-oral environment, significant changes were found in the surface topography. Using SEM, we could see porous corrosion zones and areas of friction and cracks that were visible in microscopic microspheres. These results are also confirmed by similar results from Pop and Dudescu [7].

To examine the relative corrosion rate of the alloy, it is necessary to polish the surface of the wires to a uniform finish. Polishing can harden the surface of a metal, which can then decrease the corrosion rate[8].

Exposure of archwires to an intra-oral environment can lead significant changes in their surface topography and roughness, leading to the appearance of porous corrosion areas, friction areas, and striations. Cracks and porosities visible in SEM were observed by Hunt and Golden [9]. As well, a variety of different physical, electrochemical, and biological factors may affect the mechanical and biomedical properties of the orthodontic archwires, such as saliva and occlusal and mastication forces, and modifications may also occur after the insertion of the wire into the oral cavity. Corrosion tests help to pinpoint degraded areas, along with explaining in-depth the mechanism of degradation. All of the comparisons we made of the intra-oral corrosion of the new and used archwires showed that, in most cases, the used archwires presented degraded properties after use. These results highlight the importance of localized corrosion phenomena on the surface of the used archwires and the need to know their production methods more precisely .

As shown in **Error! Reference source not found.**, frictional corrosion in the used archwires is caused by frictional forces between the bracket and the archwire interface. Kusy[10] explains the complexity of this process, which we take into consideration in our evaluation of the friction force .The deterioration developed at the interface bracket-archwire, due to factors such as partial overlapping of force areas and surface defects, changes the value of the frictional forces. The force required to overcome the supplementary friction force explains the increase in these parameters [11]. Eliades [12] asserts that after intra-oral exposure, the surface topography of archwires may be significantly altered by factors such as saliva fluid, friction, etc., with possible involvement of their biomechanical properties. Thus, by increasing the surface roughness determined by a fixed appliance, the frictional force at the bracket slot and wire interface may constantly increase [13, 14].

Comparison between new arches

The comparison shown in Table 7 is based on all new samples from each manufacturer. The comparison of the hardness shows no significant difference between the 3 manufacturers. On the other hand, for roughness there is a very significant difference between American Orthodontics and the other two manufacturers (AZ dent: <0.0001, Ortho Classic: <0.0001). The thermal analysis makes it possible to distinguish a significant difference between AZ dent and Ortho Classic (p = 0.009).

Table 7: Comparative table of new samples from each manufacturer by type of identification (P-Value)

Interactions	**Hardness**	**Roughness**
AMERICAN ORTHO x new vs AZDENT x New	0,265	**< 0,0001**
AMERICAN ORTHO x new vs ORTHO CLASSIC x New	0,475	**< 0,0001**
ORTHO CLASSIC x new vs AZDENT x New	0,978	0,429

Comparison of new and used archwires

In this part of the study, only the qualitative variables (manufacturer x use) were considered, assuming a hypothesis of homogeneity within new arches and used arches. For hardness and roughness, there were significant differences between new and used arches according to each manufacturer. On the other hand, analysis of the thermographic results did not reveal any significant differences (Table 8).

Table 8: Comparative table of new and used samples from each manufacturer by type of identification (P-Value)

Interactions	**Hardness**	**Roughness**
AMERICAN ORTHO (new x used)	**< 0,0001**	**< 0,0001**
ORTHO CLASSIC (new x used)	< 0,0001	**0,007**
AZDENT (new x used)	<0, 0001	< 0, 0001

Comparison of used arches

The comparison of used arches indicated several significant differences for each manufacturer (23/72 comparisons). The most important results involved the roughness variable. For all three manufacturers, there was a significant difference between 0.016 inch round arches and 0.016-0.022 inch rectangular arches; between the left posterior position and the anterior position; and between the right posterior position and the anterior position. The other important results were the infrared thermography, which showed significant differences between 0.016 inch round and 0.016-0.022 inch archwires for all three manufacturers.

The comparison between upper and lower was only positive for American Ortho, according to the hardness variable (p = 0.001). The comparison between men and women was positive only for American Ortho, according to the roughness variable (p = 0.042). Finally, the comparison between teenagers and adults was positive only for AZ Dent, according to variable S1 (p = 0.012), and for American Ortho, according to the variable hardness (p = 0.012) (Table 9).

Table 9: Comparative table of used samples within each manufacturer by type of identification

Interactions	A	American Ortho			Az Dent			Ortho Classic	
	Hard.	Rough. Ther (S1)		Hard.	Rough.	Ther. (S1)	Hard.	Rough. Ther. (S1)	
0.016 x 0.022 vs 0.016	**0,000**	**0,001**	**< 0,0001**	0,366	**< 0,0001**	**< 0,0001**	0,200	**< 0,0001**	**0,000**
UPPER vs LOWER	**0,001**	0,309	0,598	0,576	0,760	0,244	0,374	0,999	0,684
Women vs men	0,420	**0,042**	0,828	0,585	0,576	0,929	0,867	0,231	0,661
20-40 yrs vs 12-20 yrs	**0,012**	0,303	0,810	0,574	0,274	**0,012**	0,900	0,115	0,947
PL vs PR	0,094	1,000	0,927	**< 0,0001**	0,606	0,158	**0,001**	0,970	0,339
PL vs A	0,063	**0,041**	**0,034**	**< 0,0001**	**< 0,0001**	0,758	0,069	**< 0,0001**	0,204
A vs PR	0,984	**0,039**	**0,012**	0,853	**0,000**	0,493	0,333	**< 0,0001**	**0,006**

Study of Correlations

The statistical analysis revealed a strong negative correlation between the hardness and the results of the SEM (correlation coefficient = -0.712, p <0.0001). It also revealed a moderately weak positive correlation between roughness and SEM results (correlation coefficient = 0.391, p <0.0001). These findings indicate that the worse the state of the bow, the lower the hardness and the greater the roughness. On the other hand, there was no correlation of the periodontal state of the patients and their pathologies with the quantitative variables of this study…

CONCLUSIONS

The conclusions are as follows:

- When hardness and roughness change, shape memory and super elasticity change as well.

- For all users, there is a substantial difference between 0.016 round and 0.016-0.022 rectangular devices, with the rectangular devices deteriorating more quickly.
- In archwires, the anterior position is more prone to degradation.
- Due to saliva concentrations, germs, dental plaques, as well as occlusal forces, the used archwires lost their fundamental features of hardness and roughness.
- The mechanical and surface properties of archwires are altered when they are used intra-orally due to plastic deformations caused by their continuous use.
- By increasing the roughness of the surface, changes in the surface topography of orthodontic archwires can cause variations in the bending characteristics.
- Clinicians should monitor patients' food and hygiene habits, as well as minimize the time archwires are used intra-orally by swapping them with new archwires.

REFERENCES

1. Krishnan, M., Seema, S., Tiwari, B., Sharma, H. S., Londhe, S., & Arora, V. (2015). Surface characterization of nickel titanium orthodontic arch wires. *medical journal armed forces india*, *71*, S340-S345.
2. Prymak, O., Klocke, A., Kahl-Nieke, B., & Epple, M. (2004). Fatigue of orthodontic nickel–titanium (NiTi) wires in different fluids under constant mechanical stress. *Materials Science and Engineering: A*, *378*(1-2), 110-114.
3. Iijima, M., Ohno, H., Kawashima, I., Endo, K., & Mizoguchi, I. (2002). Mechanical behavior at different temperatures and stresses for superelastic nickel–titanium orthodontic wires having different transformation temperatures. *Dental Materials*, *18*(1), 88-93.
4. Moore, P., & Booth, G. (2015). Mechanical testing of welds, in The Welding Engineers Guide to Fracture and Fatigue, Moore, P., & Booth, G., Editors., Woodhead Publishing: Oxford. p. 113-141.
5. D'Antò, V., Rongo, R., Ametrano, G., Spagnuolo, G., Manzo, P., Martina, R., ... & Valletta, R. (2012). Evaluation of surface roughness of orthodontic wires by means of atomic force microscopy. *The Angle Orthodontist*, *82*(5), 922-928.
6. Saraç, Y., Elekdag-Turk, S., Saraç, D., & Turk, T. (2007). Surface conditioning methods and polishing techniques effect on surface roughness of a feldspar ceramic. *The Angle Orthodontist*, *77*(4), 723-728.
7. Eberle, A. L., Mikula, S., Schalek, R., Lichtman, J., Tate, M. K., & Zeidler, D. (2015). High-resolution, high-throughput imaging with a multibeam scanning electron microscope. *Journal of microscopy*, *259*(2), 114-120.
8. Pop, S. I., Dudescu, M., Merie, V. V., Pacurar, M., & Bratu, C. D. (2017). Evaluation of the mechanical properties and surface topography of as-received, immersed and as-retrieved orthodontic archwires. *Clujul Medical*, *90*(3), 313-326.
9. Lee, T. H., Huang, T. K., Lin, S. Y., Chen, L. K., Chou, M. Y., & Huang, H. H. (2010). Corrosion resistance of different nickel-titanium archwires in acidic fluoride-containing artificial saliva. *Angle Orthodontist*, *80*(3), 547-553.
10. Kusy, R. P., & Whitley, J. Q. (1997, September). Friction between different wire-bracketconfigurations and materials. In *Seminars in orthodontics* (Vol. 3, No. 3, pp. 166-177). WB Saunders.
11. Fidalgo, T. K. D. S., Pithon, M. M., Maciel, J. V. B., & Bolognese, A. M. (2011). Friction between different wire bracket combinations in artificial saliva: an in vitro evaluation. *Journal of Applied Oral Science*, *19*, 57-62.
12. Eliades, T., Eliades, G., Athanasiou, A. E., & Bradley, T. G. (2000). Surface characterization of retrieved NiTi orthodontic archwires. *The European Journal of Orthodontics*, *22*(3), 317-326.
13. Eliades, T., & Bourauel, C. (2005). Intraoral aging of orthodontic materials: the picture we miss and its clinical relevance. *American Journal of Orthodontics and Dentofacial Orthopedics*, *127*(4), 403-412.
14. Reznikov, N., Har-Zion, G., Barkana, I., Abed, Y., & Redlich, M. (2010). Influence of friction resistance on expression of superelastic properties of initial NiTi wires in “reduced friction” and conventional bracket systems. *Journal of dental biomechanics*, *2010*, 613142-613142.