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STUDY OF SURFACE TOPOGRAPHY AND ROUGHNESS OF THREE DIFFERENT TYPES ORTHODONTIC WIRES USING ATOMIC FORCE MICROSCOPY: AN IN VITRO STUDY

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Abstract— Purpose: The objective of this study was toobtain detailed 3D images of the surface at an atomic level usingAtomic Force Microscopy (AFM)to assess the topography and surface roughness of three common orthodontic archwires: St.St, CuNiTi, and super-elastic NiTi Methods and material: The sample included Thirty pieces cut from 15 archwires, all sourced from Ormco with uniform dimensions of “16x22” inches. Various roughness parameters, including Sa, Sq, and Sz were used to quantify the surface roughness. Further imaging was done using electron scan microscope (ESM) at magnification power X200, X400, X600 to capture a larger area of the surface. **Results:** There is a significant decrease in surface roughness by stainless steel group over NiTi and Cu-NiTi groups. No significant difference was found between Niti and CuNitigroups. **Conclusions:** Significant variations in surface roughness were observed among different archwire types. Detailed analysis of surface topography revealed distinct features, such as scratches, pits, and grooves, that should be avoided by optimizing manufacturing processes to minimize surface defects and improve clinical performance. Stainless steel archwires exhibited the smoothest surface with statistically significant difference than the other groups.The difference in roughness between CuNiTi and NiTi was not statistically significant.The combined use of AFM and SEM provided a comprehensive understanding of surface characteristics, from nanoscale features to microscale topography.

KEYWORDS: Surface Topography, Roughness, AFM

INTRODUCTION

Orthodontic archwires have enormous significance in conventional tooth movement. Understanding the surface characteristics, such as topography, roughness of orthodontic archwires are important determinants of the effectiveness of archwire-guided tooth movement $_{(1)}$.
Surface properties of these archwires are critical for enhancing treatment results at optimal force levels and minimizing potential loss of force due to friction$_{(2)}$.
Friction is defined as the force that resists movement of one surface against another when two surfaces come into contact,and it varies according to the nature of the two surfaces and their superficial characteristics including roughness $_{(3).}$ Frictional forces arising between the archwire

and the bracket/tube system dissipate up to 50% of the applied orthodontic force, especially during space closure(4).

Standards like ISO 4287 and ASTM B46 define surface topography by waviness (large-scale undulations), roughness (medium-to-small-scale features), and noise (small-scale features). Characterizing this multi-scale nature often requires techniques like AFM and SEM (5).

Developed in 1986 by Binnig, Quate, and Gerber(AFM) is a powerful, non-destructive technique for high-resolution, 3D imaging and characterization of surfaces, including quantitative and qualitative roughness assessment at the atomic level(6).

Only few published research in the available literature have evaluated and compared surface roughness and topography of commonly used archwires using AFM and SEM, and even when AFM is used, it is rarely combined with large-scale topography for a full description.

SEM was used in this study to overlap with AFM in their capabilities and to provide complementary information about sample's surface topography(7).

MATERIAL AND METHODS

Study design:

This in-vitro study was carried out in the National Research Centre, Operative department And Nuclear Research Center, Microscope lab. After being waived by the Research Ethics Committee of the faculty of dentistry, Suez Canal University (689/2023)

Sample size calculation:

The sample size was calculated according to G*Power software version 3.1.9.6.(8-10)

One-way analysis of variance (ANOVA), and repeated measure ANOVA is proposed.

A total sample size of 30 samples was sufficient to detect the effect size of 0.6 at a power (1-β=0.80) of 80% at a significance probability level of $p<0.05$ partial eta squared of 0.27. Where, f: is the effect size; α= 0.05; β=0.2; Power= 80%

Sample describtion:

For the purpose of standerdization, all archwires used in this study measuring 0.16x0.22" Inches, Rectangle cross section, and from Ormco brand.

Grouping of the sample:

A total of 30 samples were divided into 3 equal groups according to their type with 10samples in each group:

Group 1: Stainless steel.

Group 2: NiTi.

Group 3: Copper NiTi.

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Investigation and measurements:

Atomic force microscopy 50-micron images were taken at resolution 400 using tapping mode - rate 1 line/second.

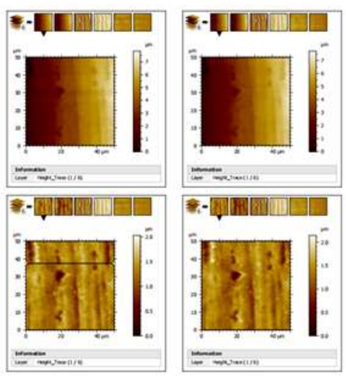
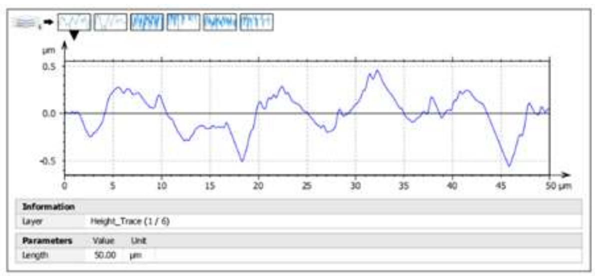
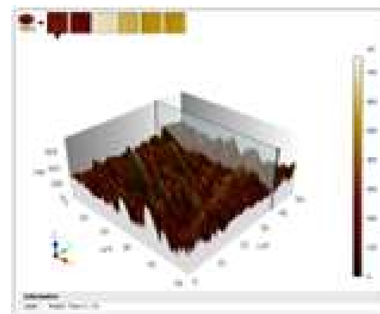
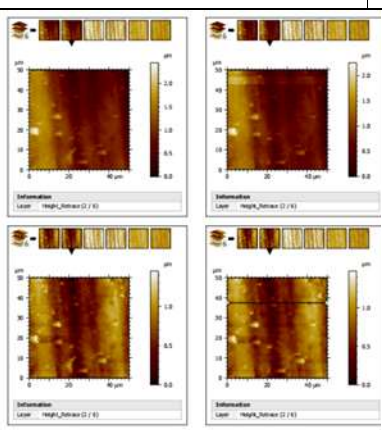
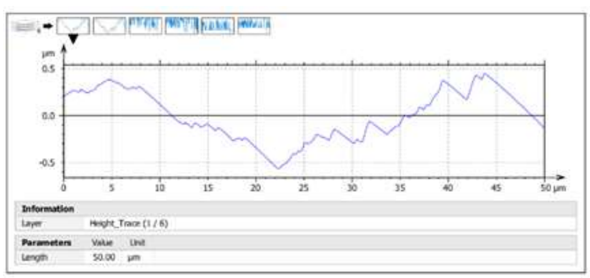
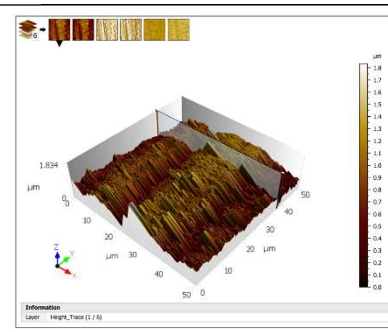
The resulting arrays of height data used to construct two, and three -dimensional (3D) images of each sample Table(1).

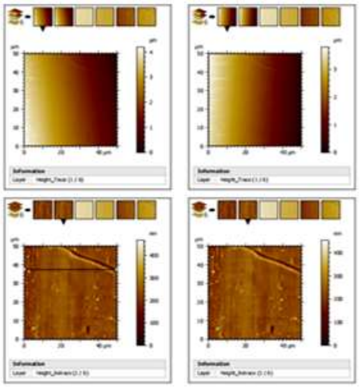
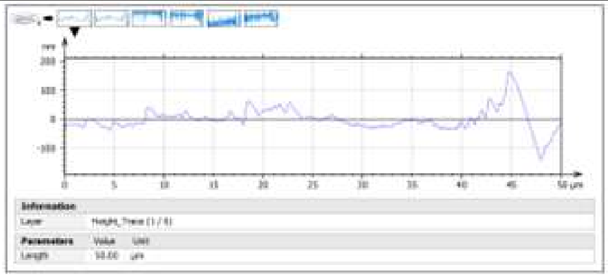
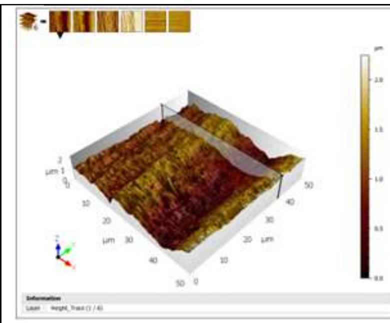
Three typically used height parameters were examined:

Arithmetic mean roughness (Sa), root mean square roughness (Sq), and maximum peak-to-valley height (Sz) (11).

comparisons between each arch wire type for each parameter were performed.

Table (1) AFM (2D,3D) imaging and hight profile of a representative sample for each group

	2D images	Hight profile	3D images
CuNiTi			
NiTi			

St.St			

SEM Scanning:

SEM was used for more complete representation of the samples and to map larger surface areas(12).

One random representative sample from each of the three groups was scanned by High-resolution field-emission scanning electron microscopy. Samples were cut then cleaned by acetone swap and handled with clean gloves, then mounted for scanning. The surface was viewed on a monitor at 200×, 400× and 600×magnifications.

Statistical analysis:

The statistical analysis was performed to evaluate the difference between three study groups. One-way ANOVA for parametric data. Data was collected, checked, revised, and organized in tables and figures using Microsoft Excel 2016. Data was subjected to outliers' detections. Data was analyzed for descriptive statistically both graphical and numerical description in terms of mean and standard deviation. Significantly different means were separated with Duncan Multiple Range Test [DMRTs (0.05)].correlation of variableswas revealed by Pearson's' correlation table.

RESULTS

AFM Results:

Arithmetical Mean Roughness (Sa): Significant differences ($p<0.001$) were found between groups. Stainless steel (Sa: 0.04±0.01 µm) was significantly smoother than copper NiTi(0.16±0.05 µm) and NiTi (0.18±0.04 µm), which were not significantly different from each other.

Root Mean Square Roughness (Sq): Similar trends were observed. Stainless steel (Sq: 0.06±0.02 µm) was significantly smoother ($p<0.001$) than copper NiTi (0.21±0.07 µm) and NiTi(0.23±0.06 µm), which again showed no significant difference.

Maximum Peak-to-Valley Height (Sz): Again, stainless steel (Sz: 0.69±0.22 µm) was significantly smoother ($p<0.001$) than copper NiTi (1.95±0.95 µm) and NiTi (1.86±0.48 µm), with no significant difference between the latter two.Fig. (1), Table (2)

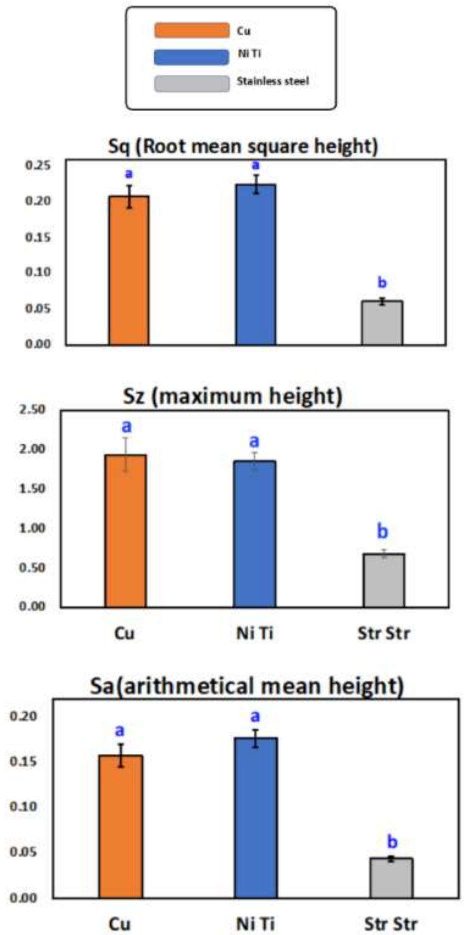


Fig. (1) Bar chart presenting the interaction all measure variable with three different groups presented as mean and standard deviation.

Table (2). All measured variable with three different groups presented as mean and standard deviation.

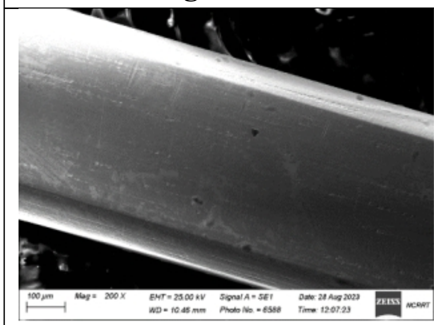
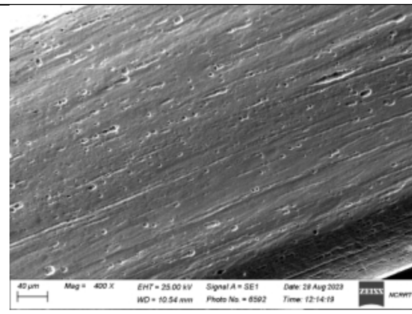
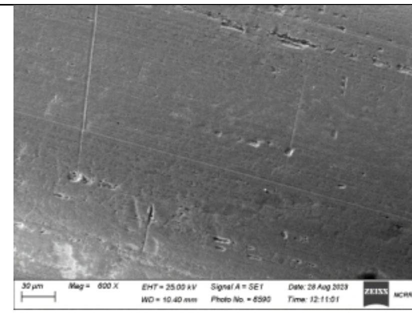
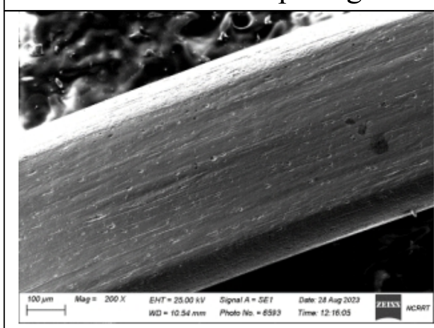
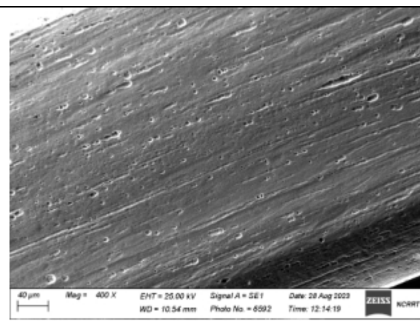
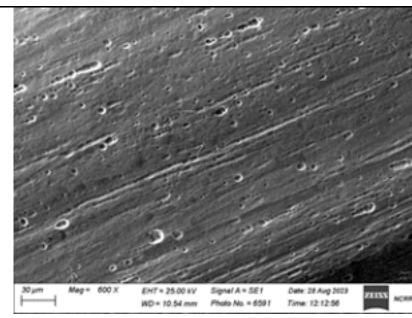
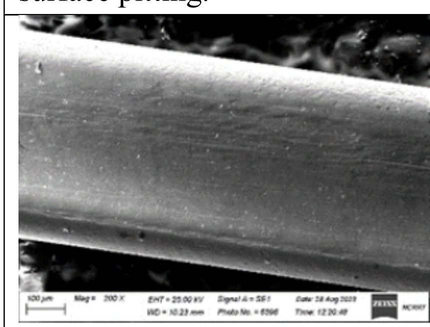
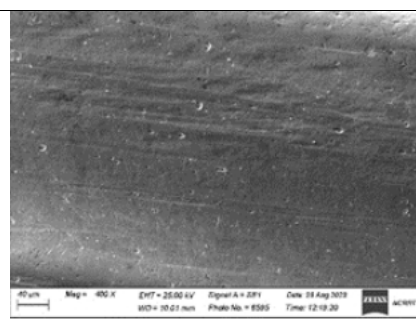
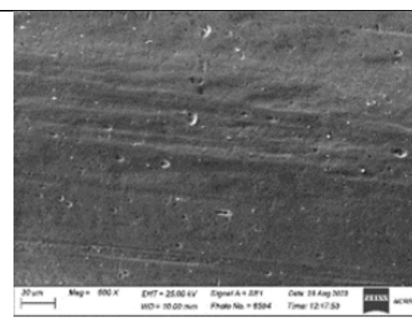
	Cu			**Ni Ti**			**St St**			**ANOVA**
	Mean	**SD**	**DMRTs**	**Mean**	**SD**	**DMRTs**	**Mean**	**SD**	**DMRTs**	**p-value**
Sa	0.16	0.05	a	0.18	0.04	a	0.04	0.01	b	<.001***
Sq	0.21	0.07	a	0.23	0.06	a	0.06	0.02	b	<.001***
Sz	1.95	0.95	a	1.86	0.48	a	0.69	0.22	b	<.001***

SEM Findings:

<table>
<tr><th>(a)

×200 magnification</th><th>(b)

×400 magnification</th><th>(c)

×600 magnification</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Fig. (2)Stainless steelShowed the least striations, primarily parallel to the long axis, with some deeper transverse scratches and wider pitting.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Fig (3)Copper NiTi Exhibited the roughest surface, with visible holes, closely spaced parallel scratches, and surface pitting.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Fig (4)NiTiPresented a relatively rough surface with parallel striations, traces of drawing, minor pitting, circular defects, and some short transverse scratches.</td></tr>
</table>

Scanning Electron Micrographs (SEM) of fig.(2) stainless steel, fig.(3)copper nickel-titanium (CuNiTi), and fig(4) nickel-titanium (NiTi) archwires. Each material is shown at magnifications of (a)200x, (b)400x, and (c)600x.

Discussion

Surface roughness of orthodontic archwires is a critical feature that is related to several aspects, including teeth movement, friction (13), bacterial aggregation, corrosion and biocompatibility, color stability, and aesthetics (14).But despite this, technically, no machining technique can achieve a particularly perfect smooth surface finish at the molecular level, and all archwires available in markets have certain roughness characteristics at various scales(15).

Since describing the multiscale nature of surface topography necessitates the use of multiple techniques, both the AFM and SEM were used (16).

The results of the present study revealed significant ANOVA differences between the groups' averages for each parameter. While Pairwise Comparisons, according to the non-significant Duncan's Multiple Range Test (DMRT) findings, suggested that there may not be enough differences between Cu-NiTi and NiTi group pairings to be recognized as statistically significant. While a statistically significant difference exist between St.St and the other two groups, Which agrees with previous study(17).

Findings of this study showed that the most statistical difference recorded between Cu-NiTi and NiTi groups was with Sz parameter while differences recorded with Sa and Sq were the least. This could be explained by the sensitivity of the Sz parameter to occasional high peaks or deep valleys compared to the more general Sa and Sq parameters.

This study confirms that stainless steel archwires exhibit the smoothest surface among the materials tested. This finding aligns with previous research (18,19,20,21,22).

Additionally, recent studies evaluating the surface roughness of several alloys found that St.Starchwires have the lowest roughness values of any material(23,24,25,26).

This result disagrees with *Amini et al.*(14)who compared St.St and NiTiarchwires made by 4 different manufacturers, and concluded that NiTi wire from American Orthodontics' was smoother than St.St of the same brand.

But This result contradicts both the earlier findings on this brand and the findings of other companies that were studied in the same research. This discrepancy may be explained by the random sampling strategy, which included items that might have been damaged during delivery or fabrication(27,28).

The AFM scans of the present study revealed that the highest surface roughness was exhibited by Cu-NiTiarchwires(17). This may be connected to the high frictional values this alloy generates. As in general, Cu-NiTi arch wires are known to have greater friction values than those of other alloys (29).

The CuNiTi results obtained in this study are consistent with the previous findings(30,31)

This result could be attributed to the microcavities formed due to the pullout of particles of NiTi and addition of Cu during the manufacturing process of alloy(32) .

Regarding superelastic nickel-titanium archwires in this study, they were found to be superior yet comparable to that of copper-nickel-titanium archwires. Which agrees with previous literature (25).

However, this result disagreed with other study (24)who found St.St to be the smoothest archwire surface, followed by CuNiTi, and concluded that NiTi is inferior to CuNiTi in terms of surface roughness.The contradictory results may be due to the use of a single method of investigation (SEM) that is less sensitive to small-scale roughness features compared to AFM used in this study (12) .

The roughness of NiTi may be related to its unique qualities of superelasticity and shape memory effect, these properties result from a phase transition between austenite and martensite, impacted by variations in force and temperature. The body-centered cubic crystal structure of the austenitic phase makes it stable at high temperatures, and lower stresses. On the other hand, the martensitic phase has a monoclinic crystal structure and is stable at high pressures and low temperatures. When heated above the austenite finish temperature, the shape memory effect allows NiTi to regain its previous shape. So, the presence of a large amount of evenly distributed pores within the NiTi structure contributes to its roughness and could explain the resulted Sz value comparing to CuNiTi(24).

A wire that is very smooth in its high temperature phase may change to a very rough one in the low temperature phase. However, dramatical changes in wire-surface structure due to the transformation of the alloy composition start between room temperature and the application temperature of 37°C (33,34).

The surface structure of orthodontic wires is influenced by various factors, including the alloy composition, manufacturing process, and surface finishing techniques(24). Consequently, the manufacturing process plays a critical role in determining the final surface topography of the wire.

Conclusion

1- Significant variations in surface roughness were observed among different archwire types.

2- Detailed analysis of surface topography revealed distinct features, such as scratches, pits, and grooves, that should be avoided by optimizing manufacturing processes to minimize surface defects and improve clinical performance.

3- Stainless steel archwires exhibited the smoothest surface with statistically significant difference than the other groups.

4- Copper NiTiarchwires had the highest surface roughness among the three types examined.

5- The difference in roughness between CuNiTi and NiTi was not statistically significant.

References

[1] **Williams,** C.L. and Khalaf, K., 2013. Frictional resistance of three types of ceramic brackets. Journal of oral & maxillofacial research, 4(4).

[2] **Kapila,** S., Angolkar, P.V., Duncanson Jr, M.G. and Nanda, R.S., 1990. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. American Journal of Orthodontics and Dentofacial Orthopedics, 98(2), pp.117-126.

[3] **Alsabti,** N., Bourauel, C. and Talic, N., 2020. Comparison of force loss during sliding of low friction and conventional TMA orthodontic archwires: An in vitro study. Journal of Orofacial Orthopedics, 82(4), p.218.

[4] **Proffit,** W.R., Fields, H.W. and Sarver, D.M., 2007. Contemporary orthodontics. Elsevier Brasil.

[5] **Jacobs,** T.D., Pastewka, L. and Guest Editors, 2022. Surface topography as a material parameter. MRS bulletin, 47(12), pp.1205-1210.

[6] **Binnig,** G., Quate, C.F. and Gerber, C., 1986. Atomic force microscope. Physical review letters, 56(9), p.930.

[7] **Ziębowicz,** B., Woźniak, A., Ziębowicz, A. and Ziembińska-Buczyńska, A., 2019. Analysis of the surface geometry of the orthodontic archwire and their influence on the bacterial adhesion. Journal of Achievements in Materials and Manufacturing Engineering, 93(1-2), pp.32-40.

[8] **Cohen,** J. (1988). Statistical power analysis for the behavioral sciences. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

[9] **Faul,** F., Erdfelder, E., Lang, AG. et al. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences Behavior Research Methods (2007) 39: 175. ttps://doi.org/10.3758/BF03193146.

[10] **Faul,** F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2013). G*Power Version 3.1.7 [computer software]. Uiversität Kiel, Germany. Retrieved from http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/download-and-register.8. Schafer

[11] **Pawlus,** P., Reizer, R. and Wieczorowski, M., 2021. Functional importance of surface texture parameters. Materials, 14(18), p.5326.

[12] **Russell,** P., Batchelor, D. and Thornton, J., 2001. SEM and AFM: complementary techniques for high resolution surface investigations. 10. Swan,

[13] **Williams,** C.L. and Khalaf, K., 2013. Frictional resistance of three types of ceramic brackets. Journal of oral & maxillofacial research, 4(4).

[14] **Amini,** F., Rakhshan, V., Pousti, M., Rahimi, H., Shariati, M. and Aghamohamadi, B., 2012. Variations in surface roughness of seven orthodontic archwires: an SEM-profilometry study. The korean journal of orthodontics, 42(3), pp.129-137.

[15] **Kapila,** S., Angolkar, P.V., Duncanson Jr, M.G. and Nanda, R.S., 1990. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. American Journal of Orthodontics and Dentofacial Orthopedics, 98(2), pp.117-126.

[16] **Jacobs,** T.D., Pastewka, L. and Guest Editors, 2022. Surface topography as a material parameter. MRS bulletin, 47(12), pp.1205-1210.

[17] **Tawfik,** M., Maaly, T. and EL-Nagar, R.M., 2020. Evaluation of surface roughness and microbial biofilm adhesion of different orthodontic arch-wires. Egyptian Dental Journal, 66(2-April (Orthodontics, Pediatric & Preventive Dentistry)), pp.727-736.

[18] **Kusy,** R.P., Whitley, J.Q., Mayhew, M.J. and Buckthal, J.E., 1988. Surface roughness of orthodontic archwires via laser spectroscopy. The Angle Orthodontist, 58(1), pp.33-45.

[19] **Bourauel,** C., Fries, T., Drescher, D. and Plietsch, R., 1998. Surface roughness of orthodontic wires via atomic force microscope, laser specular reflectance, and profilometry. The European Journal of Orthodontics, 20(1), pp.79-92.

[20] **Krishnan,** V. and Kumar, K.J., 2004. Mechanical properties and surface characteristics of three archwire alloys. The Angle Orthodontist, 74(6), pp.825-831.

[21] **Yousif,** A.A. and Abd El-Karim, U.M., 2016. Microscopic study of surface roughness of four orthodontic arch wires. Tanta Dental Journal, 13(4), pp.199-207.

[22] **Zetu,** I.N., Romanec, C., Mocanu, R.M., Cozma, D. and Ogodescu, A., 2013. Physical and mechanical properties of 5 types of orthodontic archwire. Metalurgia International, 18(8), p.184.

[23] **Alsabti,** N.I., Bourauel, C.P. and Talic, N.F., 2021. Comparison of surface topography of low-friction and conventional TMA orthodontic arch wires using atomic force microscopy. Journal of Orthodontic Science, 10(1), p.2.

[24] **Dwinuria,** Y.E., Nugroho, D.I., Sjamsudin, J. and Narmada, I.B., 2021. Comparison of Friction Coefficient and Surface Roughness on Stainless Steel Nickel Titanium, and Nickel-Titanium Copper Wires to Standard Edgewise Brackets: Experimental: in vitro: Study. Journal of International Oral Health, 13(1), pp.71-75.

[25] **Mohan,** R. and Jain, R.K., 2022. An in vitro comparative evaluation of surface roughness characteristics of different orthodontic archwires: An atomic force microscopy study. Journal of Dental Research, Dental Clinics, Dental Prospects, 16(2), p.91.

[26] **Abdulhameed,** S.A., Brijesh, S., Sunny, J., Goswami, D.S., Abraham, N. and Ambroise, M.A., 2024. Comparison of Surface Roughness of Different Orthodontic Archwires: Atomic Force Microscopic Study. Cureus, 16(1).

[27] **Prososki,** R.R., Bagby, M.D. and Erickson, L.C., 1991. Static frictional force and surface roughness of nickel-titanium arch wires. American Journal of Orthodontics and Dentofacial Orthopedics, 100(4), pp.341-348.

[28] **Shin,** J.S., Oh, K.T. and Hwang, C.J., 2003. surface corrosion of stainless steel and NiTi orthodontic appliances. Australasian Orthodontic Journal, 19(1), pp.13-18.

[29] **Anishya,** D. and Jain, R.K., 2024. Evaluation of surface roughness, cytotoxicity, and antibacterial effects of silver nanoparticle coating on copper nickel titanium orthodontic arch wires–in vitro study. Journal of Orthodontic Science, 13(1), p.31.

[30] **Gravina,** M.A., Canavarro, C., Elias, C.N., Chaves, M.D.G.A.M., Brunharo, I.H.V.P. and Quintão, C.C.A., 2014. Mechanical properties of NiTi and CuNiTi wires used in orthodontic treatment. Part 2: Microscopic surface appraisal and metallurgical characteristics. Dental Press Journal of Orthodontics, 19, pp.69-76.

[31] **Es-Souni,** M., Es-Souni, M. and Fischer-Brandies, H., 2002. On the properties of two binary NiTi shape memory alloys. Effects of surface finish on the corrosion behaviour and in vitro biocompatibility. Biomaterials, 23(14), pp.2887-2894.

[32] **Yousif,** A.A. and Abd El-Karim, U.M., 2016. Microscopic study of surface roughness of four orthodontic arch wires. Tanta Dental Journal, 13(4), pp.199-207.

[33] Buehler, W.J., Gilfrich, J.V. and Wiley, R.C., 1963. Effect of low-temperature phase changes on the mechanical properties of alloys near composition TiNi. Journal of applied physics, 34(5), pp.1475-1477.

[34] Andreasen, G.F. and Brady, P.R., 1972. A use hypothesis for 55 nitinol wire for orthodontics. The Angle Orthodontist, 42(2), pp.172-177.