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Original Research Article

Evaluation of mechanical properties of nanoparticle-coated orthodontic brackets and wires

M V Kirthi Sanjay Swaroop[1]*, Laxmikanth S M[1], Ashita Talwar[1], Sameena Begum M[1], Khadeer Riyaz[1], S R Raghavendra[1]

[1] *Dept. of Orthodontics, Oxford Dental College, Bengaluru, Karnataka, India*

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ABSTRACT

Background: Any reduction in friction between the orthodontic wire and the bracket can speed up tooth movement in the sliding technique and result in improved 3-D control. The purpose of this study was to investigate frictional forces caused by covering orthodontic wires and brackets with silver oxide nanoparticles (AgO).

Materials and Methods: In this study, 30 brackets (0.022 × 0.028" slot) and 30 arch wires (0.019 × 0.025" SS wires) were taken and split into 3 groups. The first group included uncoated arch wires and brackets. The second group included uncoated arch wires and coated brackets. The third group included coated arch wires and coated brackets. These brackets were further examined under Scanning electron microscopy to evaluate the AgO nanoparticle coating and its thickness. These brackets and wires were then subjected to a friction test with the help of a UNIVERSAL TESTING MACHINE. Frictional forces were statistically analysed using One-way ANOVA test followed by Tukey's HSD Post hoc Analysis.

Results: Coating with AgO nanoparticles significantly influenced frictional force values ($P < 0.0001$). The first group showed 0.8690 ± 0.1512 N (control).

The second group showed 0.4815 ± 0.0840 N. The third group showed 0.2010 ± 0.0445 N. This mean difference in the Frictional force between 3 groups was statistically significant.

Conclusion: AgO nanoparticles may be a unique way to dramatically reduce friction during tooth movement because of their beneficial impacts on lowering frictional forces.

1. Introduction

Orthodontics is directly related to tooth movements. One common procedure to translate a tooth in the dental arch is sliding it along an arch-wire, which is associated with advantages such as decreased clinical treatment time and 3-D control of tooth movements. Due to this sliding, friction exists between the arch wire and the bracket slot, higher forces required to overcome it, in turn resulting in the taxing of anchorage control.[1,2]

The load that is normally exerted on contact sites causes friction when the tooth-bonded brackets travel along the wire. Friction accompanies all sliding techniques and is considered an uncontrolled factor.[3] In order to induce tooth movements, it is necessary to apply mechanical forces in the range of 100-200g on the tooth. Following the application of a load on the tooth, tipping movements begin and an angle develops between the wire and the bracket's slot; when the angle reaches a certain critical range, a contact is made between the wire and bracket edges, consequently producing adhesion between the two metallic bodies. Then, the wire is subjected to a slow notching and plastic deformation; this led to the inhibition of continuous tooth

* *Corresponding author*.
E-mail address: kirthiswaroop@gmail.com (M. V. K. S. Swaroop).

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movements with numerous stops during tooth translation.[4] To overcome this problem, the applied force should increase up to 40-60% of the initial force. These increased forces increase the risk of anchorage loss, which is a major problem in orthodontics. Tooth root resorption is another main disadvantage of increased load values. To solve this issue, various methods have been developed, including the usage of wires made of various metals, forms, and sizes, the use of extra-oral forces, and the utilisation of temporary implants.[5]

Use of nanoparticles with spherical structure was introduced in the 1990s as solid lubricants. This technological achievement has been considered to decrease friction between metallic surfaces when coated on one or both surfaces.

Nanoparticles serve as spacers and limit the number of surface irregularities that come into contact with one another during the initial stage of sliding, when there is no angle between the slot and wire, resulting in a lower coefficient of friction. However, nanoparticles are released and a solid lubricant coating forms on sliding surfaces when an angle is made between the bracket and the wire and the binding process is developed.[6] Only the solid lubricant film of nanoparticles remains when the saliva is entirely forced out of the gap between the wire and the slot in higher load applications, reducing frictional forces and enabling sliding to take place.

The current study's objective was to determine how silver oxide spherical nanoparticle coatings affected the reduction of frictional forces during sliding tooth movements.

2. Materials and Methods

The study was carried out in the Department of Orthodontics, The Oxford Dental College, in collaboration with Nano Watts Technology Bengaluru.

The selection criteria included

1. 0.022 × 0.028" slot of McLaughin Bennett Trevisi (MBT) prescription central incisor brackets (Ocean North American Braces low-profile stainless-steel bracket system).
2. 0.019 × 0.025" SS wires. (JJ Orthodontics Thrissur, Kerala).
3. A mean thickness of 50 micron of silver oxide nanoparticle coating on the orthodontic brackets and arch wires.

2.1. Exclusion criteria

1. Defective wires will be excluded.
2. Defective brackets will be excluded.
3. Silver coating of thickness less than or more than 50 micro meters.

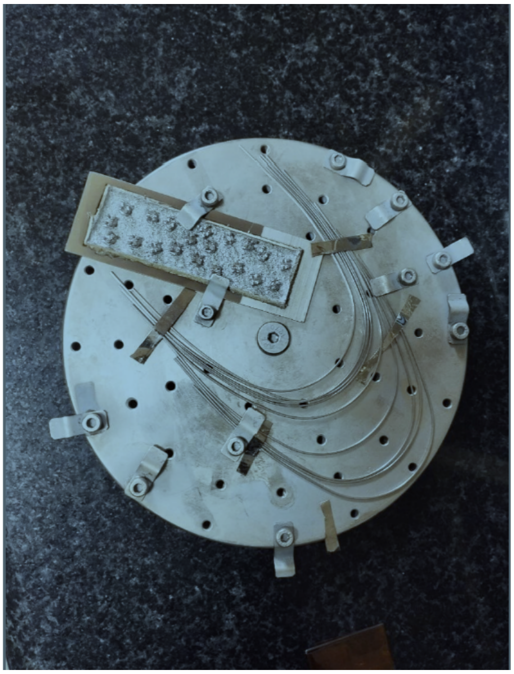

Figure 1: Image of arch wires and brackets before sputtering withAgO

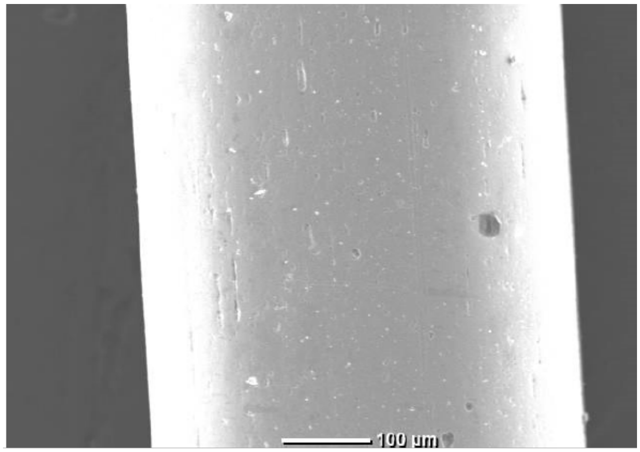

Figure 2: SEM image of wire before sputteringAgO

Procedure of surface modification of stainless-steel wires with silver particles.

The vacuum coating unit (Model No.-15 F6) manufactured by HINDHIVAC (Hind High Vacuum Co., Bangalore) was the tool utilised for coating. Vacuum Coater 15F6 creates uniform, thin, homogeneous, pure film coatings of different metals to provide controlled effects in materials, electronics, thin film coating, and optical applications. Vacuum-Coating Unit Model 15F6 from HINDHIVAC is equipped with accessories for substrate heating, rotating, film-thickness monitoring, and other features including thermal evaporation and ion cleaning

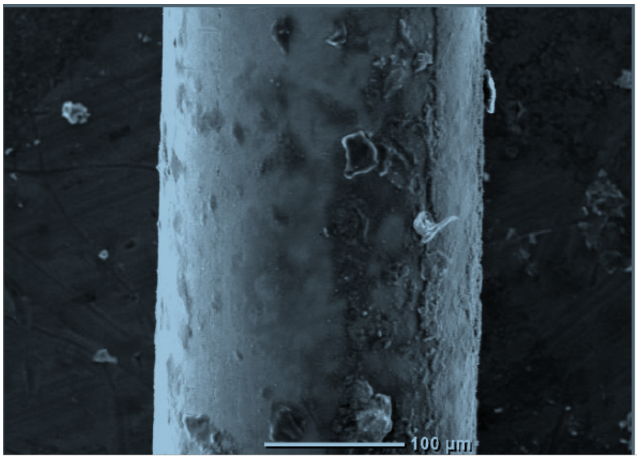

Figure 3: SEM image ofwire after sputtering AgO

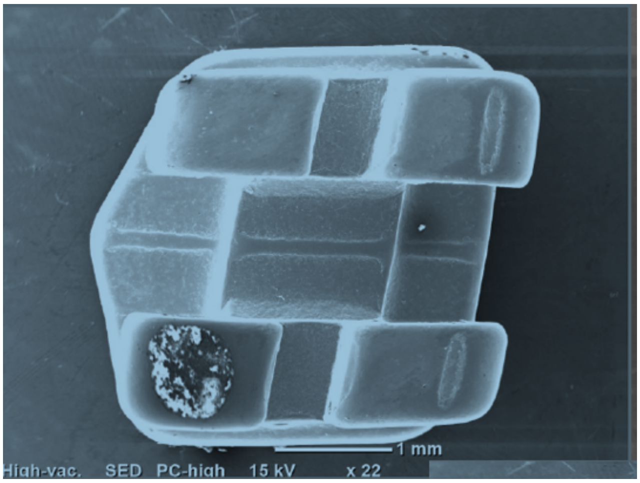

Figure 4: SEM image of bracket before sputteringAgO

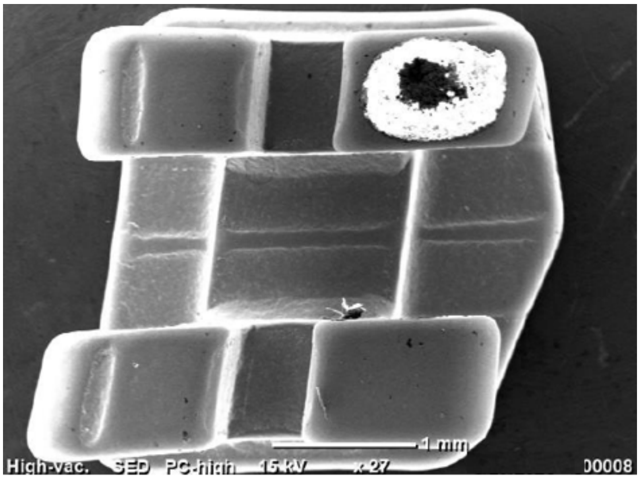

Figure 5: SEM image of bracket after sputtering Ago

Figure 6: Sputtering process

(bombardment). The thermal evaporation technique was used in this work to modify the surface of the stainless-steel wires. Pure silver (99.9%) was used to obtain thin coating on orthodontic wire. The thickness was kept constant at 10 nm for all depositions and it was measured in situ using a quartz crystal thickness monitor. The argon (Ar) gas was used as a sputtering gas (7 sccm), whose flow was controlled by the mass flow controller (MFC, AALBORG, Germany). Direct current (DC) sputtering is a thin film PVD-coating technique where a target material to be used as the coatings bombarded with ionized gas molecules causing atoms to be "sputtered" off into the plasma. When these vaporised atoms condense as a thin layer on the substrate to be coated, they are subsequently deposited. In this study, 40 W DC sputtering power and 10 milli torrent (m Torr) pressure were used.

In this study, thickness of silver nanoparticle film is kept 50 nm to avoid any significant alteration in its dimension.

The study involves a total of 30 samples, which was divided into three groups, each consisting of ten samples.

1. Group 1 - uncoated arch wires and MBT brackets.
2. Group 2 - uncoated arch wires and coated MBT brackets.
3. Group 3 -coated arch wires and coated MBT brackets.

The vacuum coater produces thin, homogeneous, uniform, pure film coatings of silver.

Friction measurements between brackets and arch wires was conducted.

The experimental procedure was done under dry conditions and at room temperature using a Universal Testing Machine (UTM MICRO MACH TECHNOLOGIES S1300 JAPAN).

The bracket with the stainless steel (SS) plate was attached to the friction testing device.

The length of the wire was 20 mm.

The wires were moved on the bracket at a crosshead speed of 0.5 mm/min. The load values of frictional resistance were measured in Newtons (N).

There was no method used to bind the wire to the bracket slot such as metal ligatures or ‘O’ rings.

These procedures were performed for all three groups, and individual readings were recorded for each bracket and wire.

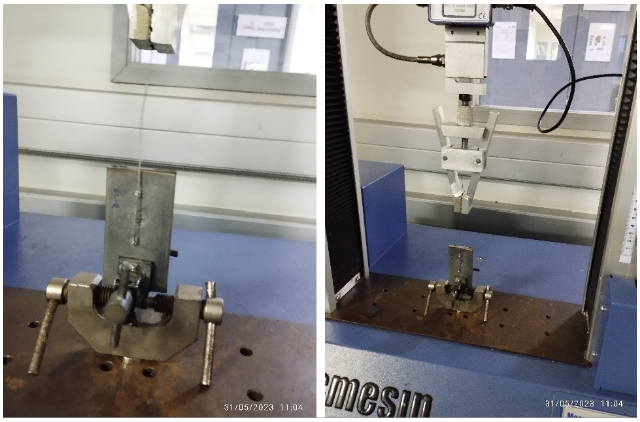

Figure 7: Universal testing machine used to carry out the friction test.

2.2. *Statistical analysis and sample size estimation*

2.2.1. *Sample size estimation*

Analysis: A priori: Compute required sample size

Input: Effect size f = 0.60

α err prob = 0.05

Power (1-β err prob) = 0.80

Number of groups = 3

Output: Noncentrality parameter λ = 10.8000000

Critical F = 3.3541308

Numerator df = 2

Denominator df = 27

Total sample size = 30

Actual power = 0.8004441

The sample size for the present study was estimated using GPower software (latest ver. 3.1.9.7; Heinrich-Heine-Universi-ta ̈t Du ̈sseldorf, Du ̈sseldorf, Germany).

The sample size estimation was performed at 5% alpha error (α = 0.05), with an effect size of 60% [Based on the findings from the previous literature, study done by Ahmad Behroozian et al, 2016] & the power of the study at 80%, revealed that a minimum of 30 samples will be necessary for the present study. So, each study group will consist of 10 samples [10 samples x 3 groups = 30 samples].

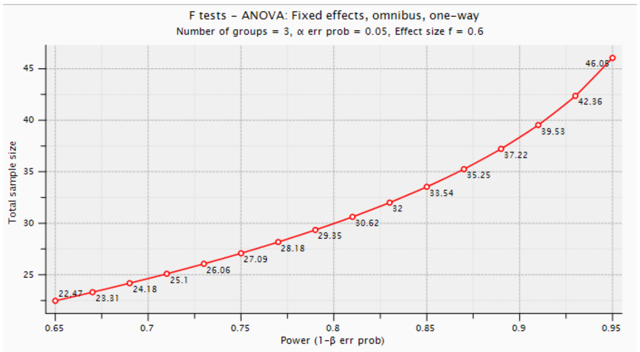

Figure 8: Power analysis curve

2.3. *Statistical analysis*

Statistical Package for Social Sciences [SPSS] for Windows Version 22.0 Released 2013. Armonk, NY: IBM Corp., will be used to perform statistical analyses.

2.4. *Descriptive statistics*

Descriptive statistics includes expression of Frictional Force in terms of mean and standard deviation (SD) for each study group.

2.5. *Inferential statistics*

One-way ANOVA test followed by Tukey’s HSD Post hoc Analysis will be used to compare the mean Frictional Force between 03 groups.

The level of significance [P-Value] will be set at P<0.05

And any other relevant test, if found appropriate during the time of data analysis will be dealt accordingly.

3. Results

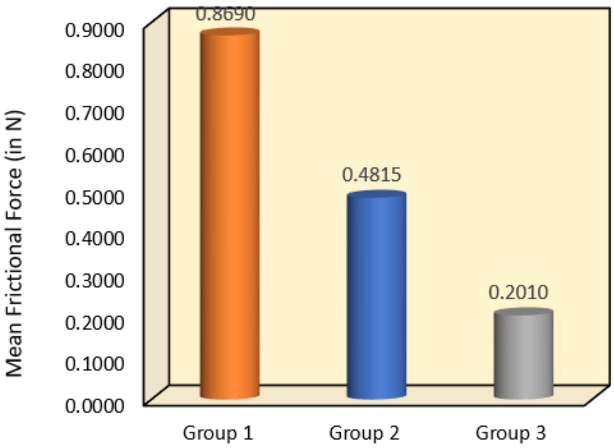

Figure 9: The graph shows decrease in friction in group 2 and group 3 as compared to group 1

Table 1: Comparison of mean Frictional Force (in N) between 3 groups using One-way ANOVA Test

Groups	N	Mean	SD	Min	Max	p-value
Group 1	10	0.8690	0.1512	0.633	1.068	
Group 2	10	0.4815	0.0840	0.337	0.574	<0.001*
Group 3	10	0.2010	0.0445	0.154	0.264	

*-statistically significant
Group 1- uncoated wires and brackets
Group 2-coated brackets and uncoated wires
Group 3-coated brackets and wires

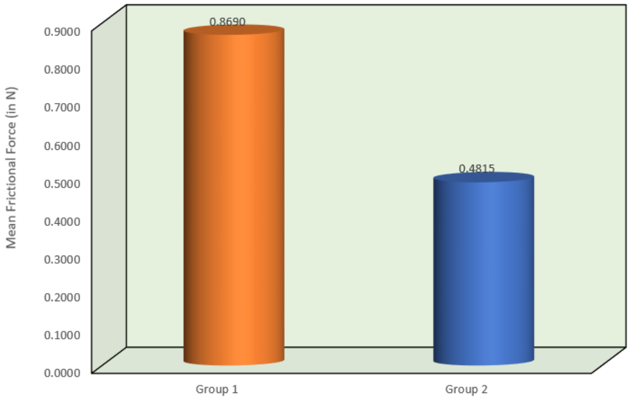

Figure 10: This shows that group 2 has decreased friction as compared to group 1

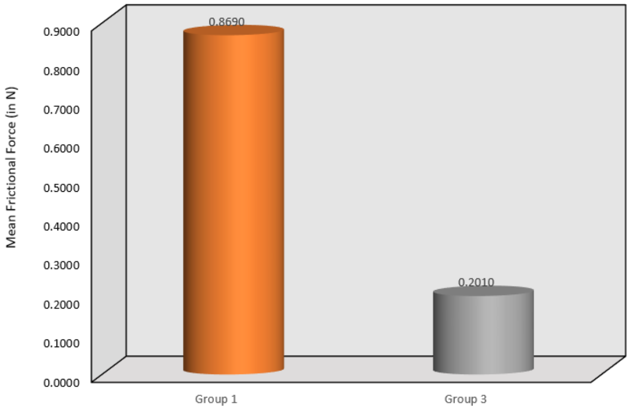

Figure 11: This shows that group 3 has significantly decreased friction as compared to group 1

The test results demonstrate that the mean Frictional force for Group 1 was 0.8690 ± 0.1512 N. Group 2 was 0.4815 ± 0.0840 N and Group 3 was 0.2010 ± 0.0445 N. This mean difference in the Frictional force between 3 groups was statistically significant at P<0.001 [Figure 9].

Multiple comparison of mean differences between groups demonstrated that Group 1 showed significantly the highest Frictional Force as compared to Group 2 and Group 3 and the mean differences were statistically significant at p<0.001. This was then followed next by Group 2

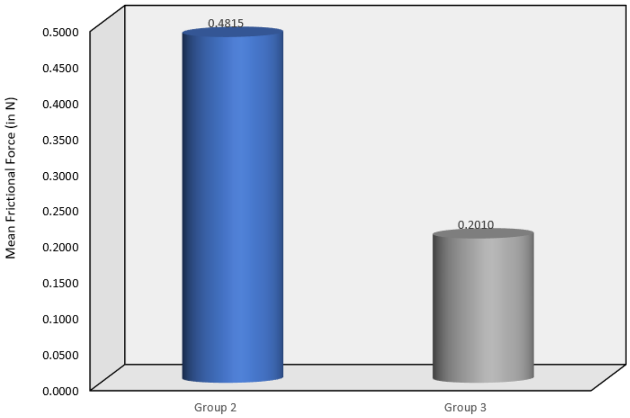

Figure 12: This shows that group 3 has decreased friction as compared to group 2

which showed significantly higher mean Frictional Force as compared to Group 3 and the mean difference was statistically significant at p<0.001. This infers that the mean Frictional Force was significantly highest in Group 1, followed by Group 2 and least in Group 3 [Figure 10]

4. Discussion

Orthodontic treatment involves applying forces to move teeth using various components like arch wires and elastics. However, when metal components or oral tissues come into contact, friction is generated. Friction control plays a crucial role in orthodontic treatment.[7] A portion of the applied force is used to overcome friction, leaving only a fraction of the force to effectively transfer to the supporting structures. Poor control of friction can result in negative outcomes, including slower tooth movement, extended treatment time.[8]

In orthodontics, silver-coated wires have been investigated for their potential antimicrobial and anti-adherent properties.[2,9] However, when introducing silver coatings to stainless steel (SS) wires, it is important to consider their potential impact on frictional resistance. By measuring the frictional resistance of these wires, the study aimed to determine whether the silver coating influenced their ability to effectively move teeth. Such information is vital for understanding the applicability and performance of silver-coated wires in orthodontic treatment.

It is important to note that further research and clinical evaluations are necessary to fully comprehend the implications and potential benefits of using silver-coated wires in orthodontics. Orthodontic treatment planning should consider various factors, including frictional resistance, antimicrobial properties, biocompatibility, and individual patient needs, to make informed decisions regarding the use of silver-coated wires and brackets.

Therefore, the aim of the present study was to assess reduction in frictional resistance using silver oxide nanoparticles coated on conventional brackets and arch wire. The results of this study reveal important insights into the frictional forces exhibited by different groups of orthodontic brackets and wires. The mean frictional force for each group was calculated and compared to assess any significant differences.

Group 1, consisting of uncoated brackets and arch wires, demonstrated the highest mean frictional force of 0.8690 ± 0.1512 N (Table 1). This indicates that when using uncoated brackets and arch wires, a relatively higher amount of force is dissipated to overcome friction during tooth movement.

On the other hand, Group 2, which involved coated brackets and uncoated arch wire, exhibited a significantly lower mean frictional force of 0.4815 ± 0.0840N compared to Group 1 (Table 1). The coating on the brackets appears to have a positive effect in reducing the friction encountered during orthodontic treatment.

Interestingly, Group 3, which was the focus of the study, demonstrated the lowest mean frictional force of 0.2010 ± 0.0445 N (Table 1). This group likely utilized a unique method of coating both the brackets and arch wire to further minimize friction. The results suggest that this specific technique employed in Group 3 was highly effective in reducing frictional forces.

The statistical analysis revealed that the mean difference in frictional force between the three groups was highly significant $P<0.001$(Table 1). These findings highlight the importance of considering the type of bracket and arch wire used and the presence of coatings or modifications to minimize friction and improve treatment efficiency.

Furthermore, the multiple comparison analysis provided additional valuable insights. Group 1 showed significantly higher mean frictional force compared to both Group 2 and Group 3 (Table 1 and Figures 9, 10 and 11), indicating that the introduction of coatings can effectively reduce friction when compared to uncoated brackets and wires.

Additionally, Group 2 demonstrated a significantly higher mean frictional force compared to Group 3 (Table 1 and Figure 12), suggesting that coating one component still has higher friction than in Group 3 where both the wire and the brackets were coated which was particularly effective in achieving reduced friction.

Overall, this study underscores the significance of frictional control in orthodontics and highlights the potential benefits of utilizing coated brackets and arch wires with innovative techniques to minimize frictional forces during tooth movement. These findings can contribute to the development of improved orthodontic treatment approaches that aim to enhance patient comfort, reduce treatment duration, and optimize outcomes.

5. Limitations

1. The present study is done in-vitro, the mechanical properties of the arch wire and brackets differ in-vivo.
2. Sample size undertaken is of limited size.
3. Methods and materials used in ligation is one of the main attributes in causing friction which has not been included in the present study, therefore future research is required.

6. Future Directions

1. Future research should include more samples and a wider demographic to test the generalization of our findings.
2. Further research should also explore the impact of varied coating thicknesses and application protocols on the effectiveness of silver oxide nanoparticles in orthodontic treatment.

7. Source of Funding

None.

8. Conflict of Interest

None.

References

1. Nikolai RJ. Bioengineering analysis of orthodontic. 1st edn.. vol. 2. Philadelphia: Lea and Febiger; 1985. p. 131–55.
2. Mhaske AR, Shetty PC, Bhat NS, Ramachandra CS, Laxmikanth SM, Nagarahalli K, et al. Antiadherent and antibacterial properties of stainless steel and NiTi orthodontic wires coated with silver against Lactobacillus acidophilus - An in vitro study. *Prog Orthod*. 2015;16:40. doi:10.1186/s40510-015-0110-0.
3. Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and arch wires. *Am J Orthod Dentofacial Orthop*. 1991;100(6):513–22.
4. Tidy DC. Frictional forces in fixed appliances. *Am J Orthod Dentofacial Orthop*. 1989;96(3):249–54.
5. Chen WX, Tu JP, Xu ZD, Tenne R, Rosenstveig R, Chen WL, et al. Wear and friction of Ni-P electroless composite coating including inorganic fullerene-WS2 nanoparticles. *Adv Eng Mater*. 2002;4(9):686–90.
6. Cash A, Curtis R, Garrigia-Majo D, Mcdonald F. A comparative study of the static and kinetic frictional resistance of titanium molybdenum alloy archwires in stainless steel brackets. *Eur J Orthod*. 2004;26(1):105–11.
7. Redlich M, Katz A, Rapoport L, Wagner HD, Feldman Y, Tenne R, et al. Improved orthodontic stainless-steel wires coated with inorganic fullerene-like nanoparticles of WS (2) impregnated in electroless nickel-phosphorous film. *Dent Mater*. 2008;24(12):1640–6.

8. Kachoei M, Eskandarinejad F, Divband B, Khatamian M. The effect of zinc oxide nanoparticles deposition for friction reduction on orthodontic wires. *Dent Res J (Isfahan)*. 2013;10(4):499–505.
9. Shah PK, Sharma P, Goje SK. Comparative evaluation of frictional resistance of silver-coated stainless-steel wires with uncoated stainless-steel wires: an in vitro study. *Contemp Clin Dent*. 2018;9(2):331–6.

Author biography

M V Kirthi Sanjay Swaroop, Post Graduate

Laxmikanth S M, HOD

Ashita Talwar, Reader

Sameena Begum M, Reader

Khadeer Riyaz, Reader

S R Raghavendra, Reader

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