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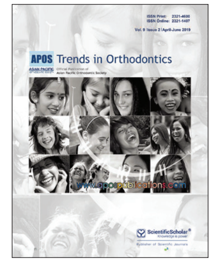

Original Article

Investigation of the effects of orthodontic brackets coated by silver hydroxyapatite, copper oxide, and titanium oxide nanoparticles on wire-bracket friction

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ABSTRACT

Objectives: Coating orthodontic brackets with metal nanoparticles seem to affect surface roughness and friction. We aim to compare the effects of coating brackets with copper oxide (CuO), titanium dioxide (TiO_2), and silver hydroxyapatite (S-HAP) on friction between brackets and various sizes and materials of orthodontic wires.

Material and Methods: In this experimental study, we selected four groups of stainless steel (SS) brackets with eight orthodontic wires (SS and nickel-titanium [Niti]) in different sizes. Three groups were coated with CuO, TiO_2, and S-HAP nanoparticles using dip coating. Then, we attached a 100 g weight to the wires and hung it from the universal testing machine. The wire passed through the brackets at a speed of 0.5 mm/min for 25 s. Finally, the friction between wires and brackets was compared using a two-way analysis of variance.

Results: The results showed that friction of brackets coated with TiO_2 was significantly lower than S-HAP ($P = 0.021$) and did not differ significantly between CuO and the control ($P = 1$). Furthermore, friction between CuO brackets was not significantly different from other groups ($P > 0.05$). Niti round wires had significantly lower friction with all brackets compared to 0.16×0.22 square inch Niti wire ($p < 0.05$), which, in turn, showed significantly lower friction compared to 0.16×0.22 square inch stainless steel (SS) wire ($P = 0.008$).

Conclusion: Coating brackets with TiO_2 and CuO nanoparticles can reduce the friction Moreover, Niti round wires show the least friction compared to rectangular or SS wires with all types of brackets.

Keywords: Nanoparticles, Titanium dioxide, Friction, Orthodontic bracket, Archwire

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INTRODUCTION

Tooth movement is an essential part of orthodontic treatment.[1,2] In fixed orthodontics, brackets (to connect to the tooth) and an archwire (to move the teeth) are used to correct the irregularity of teeth.[3,4] For tooth movement, the wire should be able to move inside the bracket, and friction opposes this ability of the wire.[5] Friction opposes the movement of two tangent objects and is equal to $\mu \times N$ (μ is the coefficient of friction and n is the normal force perpendicular to the direction of movement). A universal testing machine is used to measure friction between the wire and the bracket.[4,6-8] Friction is a multifactorial phenomenon that has advantages and disadvantages. Its advantages include preventing excessive force to move the teeth, controlling the movement of the teeth in three dimensions, low chair time, and patient comfort.[6,9,10] The disadvantages of friction also cause uncertainty in predicting the treatment results because it causes loss of useful force and consequently reduces the efficiency of orthodontic treatment.[11,12] To induce dental movements, it is necessary to apply mechanical forces in the range from 100 to 200 g on the tooth.[9,13] After applying force to the tooth, tensile movements begin, and an angle is formed between the bracket and the wire.[9,14] When such an angle reaches the threshold, contact is made between the wire and the edge of the bracket, resulting in adhesion between the metal surfaces, and then, the wire gradually bends with the permanent deformation.[15] All phenomena, in turn, prevent the tooth from moving continuously, leading to the intermittent cessation of tooth movement. To resolve such a problem, the applied force should be increased to 40–60% of the initial force.[10] On the other hand, these excessive forces lead to loss of anchorage, which is very important in orthodontic treatment. Besides, the risk of root resorption increases, and the treatment period is longer, leading to more pain.[9,11,12]

So far, different techniques have been proposed to resolve such a problem, that is, friction between the wire and the bracket,[16] the most important of which is using wire of different shapes and sizes or different chemical compounds[17-19] as well as changing features of the bracket such as changing its width, the technique of making the bracket, its material, and coating the bracket using different nanoparticles, especially metal nanoparticles.[20-22]

Metal nanoparticles have been used as solid lubricants since the 1990s.[23] To investigate the effects of these nanoparticles on frictional forces between orthodontic wires and brackets, several studies were conducted.[24,25]

One of the most important metal nanoparticles is silver, the compounds of which are chemically stable.[10,23] On the other hand, silver coatings reduce friction at high temperatures, and silver is very significant because it has the lowest contact resistance among metals. The coefficient of friction between silver and stainless steel (SS) is less than that of two SS metals.[26]

Many studies were conducted aimed to evaluate the lubricating feature of copper nanoparticles. Coated copper nano-additives can significantly improve abrasion resistance as well as reduce the coefficient of friction.[23,25,27-31] The study results of the effects of copper nanoparticles by Hu *et al*. on friction surfaces showed that reducing friction at low velocities is more than high velocities.[30]

In a study by Na *et al*., friction between the brackets coated with titanium dioxide (TiO_2) nanoparticles and wire was measured.[32] The result of this study was the reduction in friction between the bracket and the wire, which reduced the duration of orthodontic treatment and better treatment outcomes. Furthermore, in a study by Wu *et al*., TiO_2 nanoparticles reduced the coefficient of friction by a protective layer on abrasive surfaces and are used as lubricants.[32,33] Hydroxyapatite is crystalline calcium and phosphate which was widely used in biomedical and dental fields due to its properties such as similarity to the main mineral part of hard tissues of the human body and biocompatibility.[34,35]

There are different methods for depositing these nanoparticles on bracket and wire surfaces, which differ in multiple studies including the use of plasma-based ion coating/deposition,[36] electroplating,[32] plasma-enhanced chemical vapor deposition[37], and dip coating in the present study from which we benefit as it is inexpensive, has low processing temperatures; relatively cheap as coatings are very thin and high purity.[23]

No study has been conducted aimed to compare frictional effects of silver hydroxyapatite (S-HAP), copper oxide (CuO), and titanium oxide (TiO) nanoparticles on orthodontic brackets with different types of orthodontic wires. Hence, we aim to compare the friction between these brackets and investigate the different types and sizes of the arch wire.

MATERIAL AND METHODS

This study was conducted after receiving the code of ethics (IR.SEMUMS.REC.1399.099) from Semnan University of Medical Sciences. In this experimental laboratory study, 20 SS brackets (American Orthodontics, Florida, USA) similar in the type of tooth (mandibular premolars) and manufacturer were purchased. Five brackets were randomly coated by CuO (Laboratory of the Faculty of Physics, University of Tehran), five brackets were coated by TiO (Laboratory of the Faculty of Physics, University of Tehran), five brackets were coated by S-HAP nanoparticles (Tehran Atomic Energy Center), and five brackets were investigated as a control group with no intervention. Eight archwires (Ortho Technology, Tampa, Fla) of two different materials, SS and nickel-titanium (Niti), with no coating matter, were also selected in two round cross-sections in sizes 012 inches (Based on a study conducted by Baccetti *et al*., we used the 012 inch Niti archwire as the wire with the lowest friction which can be usually used in the first stages of orthodontic tooth alignment)[38] and 018 inch and rectangular cross-sections in sizes 016 × 022 square inches and 019 × 025 square inches.

The studied brackets were made of SS with standard slot size 022 in the Roth system.

Scanning electron microscopy (SEM) (SEM, KYKY-EM3200, China) was used to measure the size of nanoparticles (<100 nm and ×1000) [Figure 1]. We used the dip-coating method on SS brackets. Coating of nanoparticles on surfaces is called to form a layer with a thickness of nanometers using different methods (including dip coating)[23] and thickness of

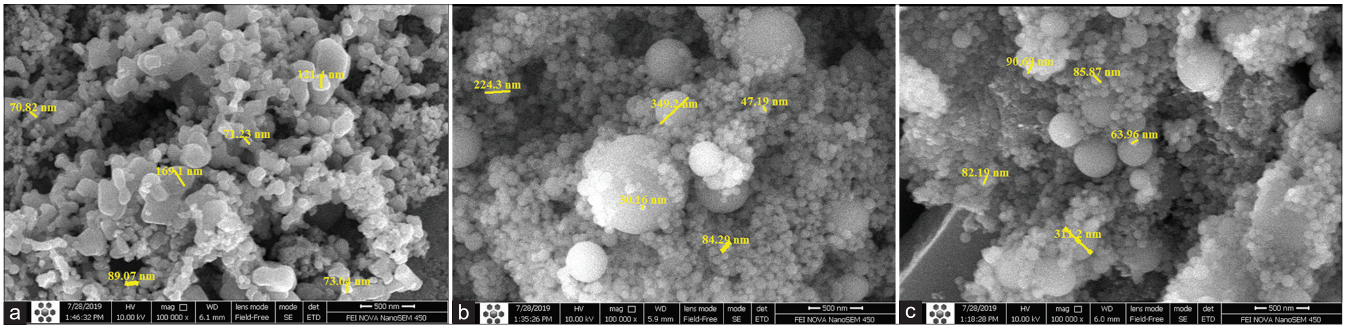

Figure 1: Measurement of nanoparticle size by scanning electron microscope (a. TiO_2, b. CuO, c. S-HAP). CuO: Copper oxide, TiO_2: Titanium dioxide, S-HAP: Silver hydroxyapatite.

the layer by the dip-coating method as a single layer can be molecules. Then, an atomic force microscope (AFM) (AFM, Flex AFM, Switzerland) was used to determine the thickness of nanoparticles.

To determine friction between the archwire and the brackets, the following measures were taken: First, we made a frame to place the brackets inside the machine (SANTAM STM 20 – SAHAND Co., Iran) using the stick and wood glue. Our frame consisted of eight sticks which were divided into two (n = 4) groups and each of them was connected by wood glue and fixed on both sides of the machine with a width of 45 mm. Another stick was selected to attach the brackets. The brackets were bonded to stick at approximately 10 mm intervals horizontally so that the guide groove inside the brackets was inserted vertically into the machine [Figure 2].

The orthodontic archwires were connected one by one to 100 g[9] equivalent weight of each bracket to be tested inside each bracket. Then, the weight-bearing wire was passed through the guide groove of the desired bracket, and to record friction by the machine, the archwire was held inside the brackets by rubber straps called O-ring (Leone® Spa); finally, hanged 100 g weight wire from the machine. Ligation can be done using SS ligature wires, which provide a secured tie of the archwire, lesser friction, and a slower rate of force decay compared to the elastomeric modules, which, in turn, are easier to place and take lesser chair side time. As several studies have shown their greater amount of wire-bracket friction compared to SS ligatures, we decided to study the effects of covering brackets with different nanoparticles to evaluate the changes in friction using the ligation technique with the highest amount of friction (elastomeric ones).

The machine moved the archwire through the bracket slot at a speed of 0.5 mm for 25 s,[9] during which static friction (starting or static friction) was measured and recorded by the computer connected to the machine, in which static friction, that is, the maximum value, was compared and investigated. STM 20 is used for doing tensile, compression, and bending tests (in low loading), and the relative applications. Due to the existing variety of tools and various accessories with relative software (easy operation STM Controller and JADOO), tensile, compression, bending, and friction tests will be provided. Accurate extension control through encoder feedback with high resolution (0.001 mm) and the accuracy of 0.05 mm to precisely constant test speed and wide range of grip speed will allow an operator to do a test of various fields. However, in the present study, we did not mention details about kinetic friction as we compared the static one between different groups.

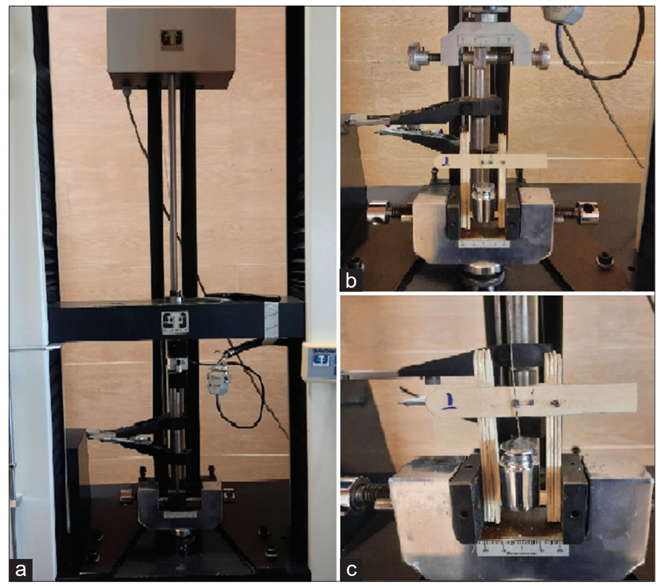

Figure 2: (a) Method of friction measurement using a universal testing machine. (b) Holding the bracket on a stick. (c) Passing 100 g weight wire through the groove of the bracket.

Eight wires were passed from each bracket to record friction and reduce the percentage of possible error. In general, the friction test was performed 160 times. The data were analyzed using Shapiro–Wilk test, one-way analysis of variance, two-way analysis of variance, and Bonferroni multiple comparison test. The software SPSS 23.0 was used and the significance level was 0.05.

RESULTS

The results of two-way analysis of variance showed that type of nanoparticle (F [3,128] = 5.67, $P = 0.001$, $\eta^2 = 0.117$) and wire (F [7,128] = 6.94, $P < 0.001$, $\eta^2 = 0.275$) had a significant effect on friction. The interaction between nanoparticle and wire type was also significant (F [21,128] = 2.85, $P < 0.001$, $\eta^2 = 0.319$). This means that friction of various types of nanoparticles can vary based on the type and size of the arch wire used. The results of one-way analysis of variance of 32 different combinations (four groups and eight arch wire types) showed a significant difference in friction (F [31,128] = 4.05, $P < 0.001$).

A) Comparison of nanoparticles

[Table 1] shows that in all types of studied wires, the total mean friction with TiO_2 nanoparticles was significantly lower than S-HAP nanoparticles ($P = 0.021$) and did not differ significantly with two groups of CuO ($P = 1.00$) and the control ($P = 1.00$). Furthermore, mean friction in the CuO group was not significantly different from any other groups ($P > 0.05$). The mean friction in the control group was significantly lower than in the S-HAP nanoparticles group ($P = 0.001$).

B) Comparison of various archwires

Niti 012 inch and Niti 018 inch orthodontic archwires resulted in significantly less friction in the bracket than Niti 016 × 022 square inch archwires [Table 2] ($P < 0.001$). SS 012 inch orthodontic archwire caused significantly less friction compared to Niti 016 × 022 square inch ($P < 0.001$) and Niti 019 × 025 square inch ($P = 0.031$) archwires in the bracket [Table 2]. Friction between the Niti 016 × 022 square inch archwire and the bracket is less than the SS 016 × 022 square inch archwire ($P = 0.008$) [Table 2]. In addition, friction in SS 019 × 025 square inch archwire was significantly more than Niti 012 inch ($P = 0.046$) and Niti 018 inch ($P = 0.018$) archwires [Table 2].

DISCUSSION

In the present study, three nanoparticles of CuO, TiO_2, and a combination of S-HAP were used to coat the surface of orthodontic brackets to measure the effects of these nanoparticles on wire-bracket friction. The results showed that in all wires studied, total means friction with TiO_2 nanoparticles is significantly lower than S-HAP nanoparticles ($P = 0.021$) and did not differ significantly with two groups of

Table 1: Mean and standard deviation of friction (N) between brackets coating with three types of nanoparticles (CuO, TiO_2, and S-HAP) and wire of different size and materials.

Type of wire	Type of nanoparticle			
	TiO_2	CuO	S-HAP nanoparticles	Control
Niti 012 inch	0.12±1.28	0.07±0.84	0.04±0.85	0.14±1.01
Niti 018 inch	0.08±0.85	0.15±1.04	0.07±1.02	0.12±0.94
Niti 016×022 square inch	0.23±1.53	0.16±1.48	0.14±1.89	0.07±1.17
Niti 019×025 square inch	0.21±1.34	0.13±1.10	0.16±1.37	0.24±1.43
SS 012 inch	0.08±0.82	0.07±1.10	0.10±0.95	0.06±0.85
SS 018 inch	0.09±1.14	0.27±1.01	0.15±1.65	0.16±0.98
SS 016×022 square inch	0.19±1.01	0.12±1.10	0.13±1.17	0.11±1.09
SS 019×025 square inch	0.23±0.85	0.22±1.64	0.36±1.87	0.19±0.79

CuO: Copper oxide, TiO_2: Titanium dioxide, S-HAP: Silver hydroxyapatite, Niti: Nickel-titanium, SS: Stainless steel

Table 2: *P*-value of comparing mean friction of different types of wires.

	Niti 012	Niti 016×022	Niti 018	Niti 019×025	SS 012	SS 016×022	SS 018	SS 019×025
Niti 012	-	-	-	-	-	-	-	-
Niti 016×022	<0.001	-	-	-	-	-	-	-
Niti 018	1.00	<0.001	-	-	-	-	-	-
Niti 019×025	0.186	1.00	0.077	-	-	-	-	-
SS 012	1.00	<0.001	1.00	0.031	-	-	-	-
SS 016×022	1.00	0.008	1.00	1.00	1.00	-	-	-
SS 018	1.00	0.149	1.00	1.00	0.600	1.00	-	-
SS 019×025	0.046	1.00	0.018	1.00	0.600	0.542	1.00	-

Niti: Nickel-titanium, SS: Stainless steel

CuO (P = 1.00) and the control (P = 1.00). In some studies, the antimicrobial effect of different nanoparticles along with the effects on friction is measured simultaneously.[34,39,40] In some studies, nanoparticles are coated on the orthodontic archwire,[15,17] or the wire and the bracket are both coated together.[9,15] Other studies, in addition to friction, measured and investigated mechanical properties of nanoparticles including surface roughness, conductivity, kerogen, and effects on shear strength given that the type of nanoparticles will also be different in each study.[22,23,35,41-43] To measure friction, eight types of archwires in two types of SS and Niti were used at the cross-sections of 012 inches, 016 inches, 016 × 022 square inches, and 019 × 025 square inches.

The results of the present study showed that the coated brackets by TiO_2 nanoparticles as well as the control group brackets that do not contain any coating material are more effective in reducing friction between wires (more than 80% of wires) and brackets than the group of brackets containing S-HAP nanoparticles. The mean friction in the S-HAP nanoparticle group is not significantly different from the CuO group. Moreover, mean friction in the CuO group is not significantly different from any of the groups. The results also showed that friction in different types of particles depends on the type of wire, which according to this result while considering the same nanoparticles coated in the CuO group, mean friction in this group varies according to the wire size and friction of wires with a rectangular cross-section is higher than that of round wires. This conclusion is also true in TiO_2 and control groups but is not significant ($P > 0.05$). The difference observed in the amount of wire-bracket friction can be explained by their microscopic crystalline structure as coating brackets using TiO_2 resulted in a smoother surface compared to the other two coating materials. The crystal structure of TiO_2 was smaller than that of the other two matters and its biofilm thickness was less, which reduced friction well.

Other factors affecting friction are the formation of an adhesive layer of biofilm and macromolecules in saliva. As a result, regeneration of oral conditions, including placing brackets in a humid and salivary medium, can change the results.[22] For orthodontic treatment, because the brackets are usually placed inside the oral cavity for a long time, from 6 months onward, the coating layer of the brackets can prevent the formation of cariogenic biofilms under poor oral hygiene conditions and to some extent reduce adverse effects on friction.[41] Other factors such as eating or brushing may affect static friction between the bracket and the wire.[22,41]

Na *et al*., in a study on the properties of TiO_2, found that TiO nanoparticles have excellent antibacterial properties. Besides, TiO can reduce friction between the bracket and the wire.[32] Such as this study, the total mean friction in the TiO_2 group was lower than the control group, but no significant difference was found. This finding was similar in other studies, which can be attributed to the type of nanocrystalline structure of metal oxide TiO_2[32,33] compared to the combination of S-HAP nanoparticles, which, in the present study, showed the highest friction compared to the control group. In this study, the lowest thickness of TiO2 nanoparticles formed on the surface of the bracket can be considered by electroplating. We can even mention the level of surface roughness formed using this metal oxide, which is comparable to other nanoparticles on a microscopic scale. Due to its antibacterial properties as well as the evidence in this study and the present study to reduce friction,[32] this combination can be an ideal orthodontic treatment by increasing efficiency and reducing time.

Arash *et al*. coated 15 brackets by silver ions electroplating method and compared them with 15 uncoated steel brackets. Silver coating led to higher friction forces in the archwire.[10] Like the present study, the S-HAP coating was not an effective way to reduce friction in the lubrication mechanism. The silver nanoparticles were coated in combination with hydroxyapatite due to their antibacterial effect.[44] Finally, our results showed that coating with S-HAP nanoparticles significantly led to higher mean friction than the control group, which confirmed the results of the above study. One of the factors affecting friction of silver-coated brackets is the coating method, which was electroplating while we used dip-coating which affects the thickness of the coating layer and thus the friction. The differences in the study results in the mouth and the present study performed in the laboratory should also be noted.[10,22,41] Therefore, silver, whether alone or in combination with hydroxyapatite, despite having an antibacterial effect, is not ideal for the first stages of orthodontic treatment (alignment), because it increases friction and consequently the treatment time by reducing the rate of tooth movement.

Desai *et al*. lined 40 SS wires with epoxy coating and ceramic brackets with metal slots using four different methods under humid conditions (artificial saliva) using different ligatures.[41] Under the same laboratory and clinical conditions, if TiO_2-coated brackets were combined with ultra-smooth modules and used in the buccal teeth, they reported a reduction in friction between the wire and the bracket and improvement of orthodontic treatment.

Bącela *et al*. studied various methods of additives such as silver nanoparticles and nitrogen-doped TiO_2 to orthodontic brackets on antimicrobial properties and friction measurement.[22] In this study, as in the present study, silver and TiO_2 nanoparticles[22,32,33] were used to investigate friction and the results showed reduced friction and bacteria accumulation around the orthodontic brace.

Similar to the results of the present study, anti-frictional properties of CuO nanoparticles were shown in Wang *et al*. study as they reported wonderful anti-wear, reducing friction, and self-repairing performances of nanoparticles of CuO.[25]

Regarding differences *in vitro* and the patient's mouth, the patients show different degrees of crowding and irregularity of teeth, and the duration of treatments will be different in different groups of patients.[6,45] It is suggested to measure mean friction in S-HAP, CuO, and TiO nanoparticles composite on brackets in future studies under clinical conditions. Other methods should also be considered for coating these nanoparticles, different types of brackets self-ligating or ceramic brackets, archwires, and different methods of ligation. In addition, successful coatings of wires and brackets or both with the same results in different studies should be compared (for example, different coatings of both appliances that reduce friction). More accurate methods to measure the angle should be applied because the angle will be effective in reducing or increasing friction; finally, more samples should be investigated to reduce the chance of results.

CONCLUSION

Coating of the brackets with different nanoparticles affects the wire-bracket friction. The total mean friction in the TiO_2 group was significantly lower than in the S-HAP nanoparticles and was not significantly different from the CuO and the control groups. Regarding the wire cross-section and material, round Niti wires are ideal for primary stages of orthodontic treatment where lower friction is desirable to meet the irregularities while SS rectangular wires are recommended for the final stages to correct the details and control root movements.

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Declaration of patient consent

Patient consent is not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

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