# Comparison of friction between ceramic brackets and ZnO nanoparticle coated wires

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**Abstract:**
**Aim**: Sliding a tooth along an archwire involves a frictional force, causing a number of adverse effects like anchorage loss, excessive orthodontic forces, prolonged treatment time and damage to the roots. This is especially true in ceramic brackets where the friction is notoriously higher.Recently, wire coating with the different nanoparticles has been proposed to decrease the frictional forces. This study evaluated the friction force created between stainless steel archwires coated with ZnO nanoparticles and ceramic brackets in vitro.
**Materials and Methods:** Friction tests simulating archwire functioning of the coated and uncoated wires and ceramic brackets were carried out by an Instron machine.Control and case groups included uncoated and coated 0.019×0.025 stainless steel wires respectively. Coating was preformed by inserting stainless steel (SS) wires into solutions of ethanol + zinc oxide. The adhesion properties of the coated wires after friction were analyzed by SEM (scanning electron microscope).The frictional forces were compared usingMann-Whitney test.
**Results**: In the control group (porcelain brackets + uncoated stainless steel wires) the mean friction force was 2.59 ± 0.37N whereas in case group (porcelain brackets + coated stainless steel wires) the mean friction force was 2.54 ±0.32 N. Although the friction force in coated wires was lower than uncoated wires; the difference between two groups was not statistically significant. ($p$=0.62).
**Conclusion**: coating of stainless steel archwires with ZnO nanoparticles did notcause significant reduction in frictional forces between stainless steel arch wires and ceramic brackets.
**Keywords:** Zinc oxide nanoparticles, Friction, Orthodontic wires, Porcelain Brackets
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One common procedure to translate a tooth in the dental arch is sliding it along an archwire that offerssome advantageslike decreased clinical treatment time, patient satisfaction, and three-dimensional control of the tooth movements.[1]Whenever sliding occurs, a frictional type force is encountered. Friction is defined as the force resisting the motion of a body relative to another, and it operates in the opposite direction of the motion.

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Because the orthodontic force must overcome the frictional resistance, minimizing friction will result in reduced levels of the clinically applied force needed for moving the teeth.
Such a reduction might shorten the treatment period or improve anchorage control. However, a frictional force between the bracket and wire is unavoidable in sliding procedure with higher forcesand requiringovercoming it which faces the anchorage control with some risks in turns.[1-4]In the orthodontic treatments, when the tooth-bonded brackets move along the wire, friction results from the load naturally applied on the contact points.[5] Friction accompanies all sliding techniques and is

considered as an uncontrolled factor.[1,6]In the sliding techniques, tooth movement occurs in the manner of tipping and uprighting with no linear pattern. Following the application of a load on the tooth, tipping movement begins and an angle develops between the wire and the bracket's slot.When the angle reaches a certain critical point it makes a kind of adhesion between two surfaces. Then, the wire, subjects to notching and plastic deformation slowly; all these procedures lead to the prohibition of tooth movement.6Since the orthodontic force must overcome that frictional

Resistance (which is nearly twice the force level requiredto cause bone remodeling to allow tooth movement) minimizingfriction will result in reduced levels of the clinicallyapplied orthodontic force. Such a reduction might improveboth anchorage control and direction of tooth movement. Itcan also reduce the risk of apical root resorption and may evenshorten the treatment duration.[7, 8]

Suggested solutions to overcome this friction includes changing the dimension or shape of the wire, using of low friction brackets ,as well as application of extraoral forces or using temporary implants.[8] Furthermorenanoparticles have been emphasized to decrease the frictional forces between two metallic surfaces as excellent solid lubricants.[9-11] In order to utilize this characteristic of nanoparticles to decrease the friction during orthodontic treatments, the orthodontic wires can be coated with the nanoparticles.9Redlich et al. (2008) coated 0.019×0.025 stainless steel orthodontic wires with inorganic fullerene-like nanoparticles of tungsten disulfide ($WS_2$) and showed significant reduced frictional forces on the wires.[9] Furthermore, the stainless steel orthodontic wires when coated with the nanoparticles of CNx as suggested by Wei et al.[12] showed significant decrease in frictional forces.Gotoetal.[13] demonstrated a reduction in the frictional coefficient of the ZnO coated stainless steel substrate in the vacuum. Eskandarinejadetal. found that coating of stainless steel wire cause significant reduction in frictional forces in stainless steel wire –bracket combination. [14]

Appropriate benefits of the nanoparticles are related to the followings:

- Rolling effects that cause two surfaces to slide on each other due to the particles sphere-like shape.
- Nanoparticles serve as spacers, preventing the contact between the two mating surfaces.
- Third body material transfer, who only occurs when the nanoparticles release from the coating surfaces by electroless procedure and transfer to the opposing substance (bracket). [9-11, 15]

In the first stages of sliding, when there is no angle between the slot and wire, nanoparticles act as spacers and decrease the number of asperities which come in contact with each other causing a reduced lower coefficient of friction. However, when an angle is created between the bracket and wire, and the binding process is developed, the nanoparticles are released and a solid lubricant film is formed on the sliding surfaces. In the higher loads applications, the saliva is pushed out of the gap between the wire and slot completely and it is only the solid lubricant film of the nanoparticles to decrease the frictional forces and allow the sliding to occur. [9-11,15]

Obviously, future clinical use of the coated wires will be subjected to the safe biocompatibility tests according to accepted procedures.Considering possible toxicity of $WS_2$, new self-lubricating coatings other than $WS_2$ is needed to be prepared and analyzed.

With esthetic reasons ceramic brackets have been more popular but the frictional forces are significantly higher in these brackets compared to stainless steel brackets.[16]

The objective of the present study was to assess the effect of spherical zinc oxide nanoparticles coating of stainless steel on friction reduction in sliding tooth movement between ceramic brackets and stainless steel wires.

**Materials and Methods**

In this laboratory experimental trial, two groups were considered. The case group included orthodontic wires 0.019×0.025 (AmericanOrthodontics, Sheboygan, Wis) with ZnO nanoparticles coating and porcelain brackets of the upper right centrals in 0.022 standard system (orthotechnology, USA) whereas in control group the wires were not coated with ZnOnanoparticles. Each group contained 30wire – bracket combination.

For coating of zinc oxide nanoparticles on wire, the wires were stored in the ultrasonic bath of ethanol solution for 30 minutes at 30 °C temperature at first. Then, 0.1 g of zinc oxide nanoparticles were added to the experimental tube containing ethanol solution and transferred to the water bath at 80 °C temperature after mixing. Nanoparticles were completely distributed into the ethanol solution and then stainless steel wires immersed in the solution. According to the previous study 10 minutestime immersion of the wires was selected.[14] SEM images of the wires approved ZnO nanoparticles coating in this method (Fig1).

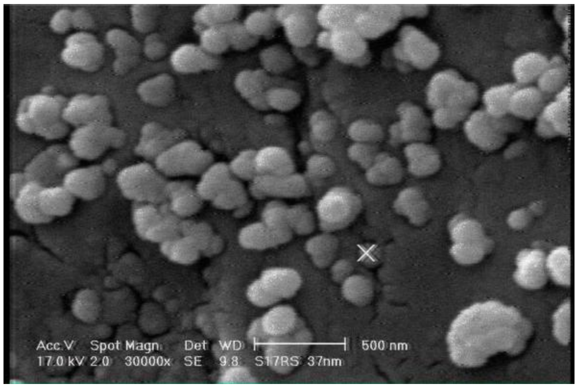


**Fig 1- SEM image of a wire coated with zinc oxide nanoparticles**

Each bracket was bonded with a cyanoacrylate adhesive to an aluminum plate with a bracket-mounting apparatus .We used a certain device that designed for this study to mount the brackets exactly in 0 degree on the aluminum plate (Fig 2), especially designed for this study; this allowed similar and accurate positioning of the bracket on the plate.

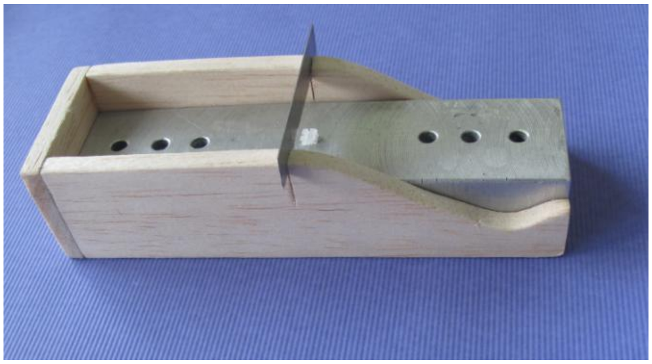

**Fig2-the aluminum plate and the bracket-positioning device**

Then the plate was fastened with screws to a notch in a special device, also built for this study; it was then attached to the base of an Instron testing machine (Universal Testing Machine 4502, High Wycombe, United Kingdom).Segment of 15-cm archwire was ligated to the brackets with an elastomeric module (orthotechnology, USA). The upper end of the wire was inserted into a tension load cell of the testing machine, and a 150-gr weight was attached to the lower end of the wire (Fig 3).

Each wire was drawn through the bracket at a constant speed of 10 mm/min for a distance of 10 mm. Each group contained 30 segmented wires and 30porcelain brackets, for a maxillary right central incisor, with 0.022 x0.028-in slots, as follows. For each test a new bracket–wire combination were used and mean frictional forces were registered (Fig 4).

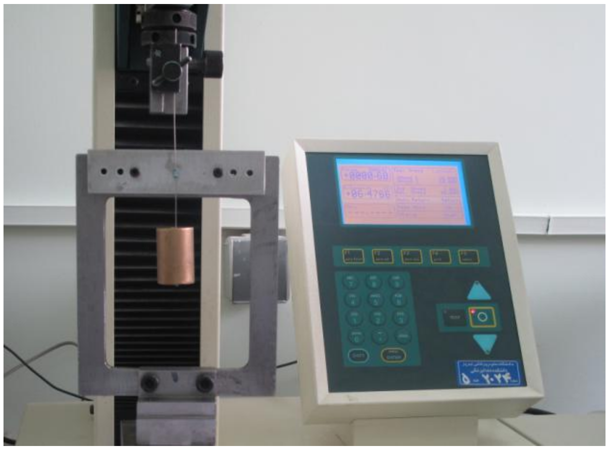

**Fig 3- Instron testing machine is pulling the wire thorough porcelain bracket mounted on the aluminum plate**

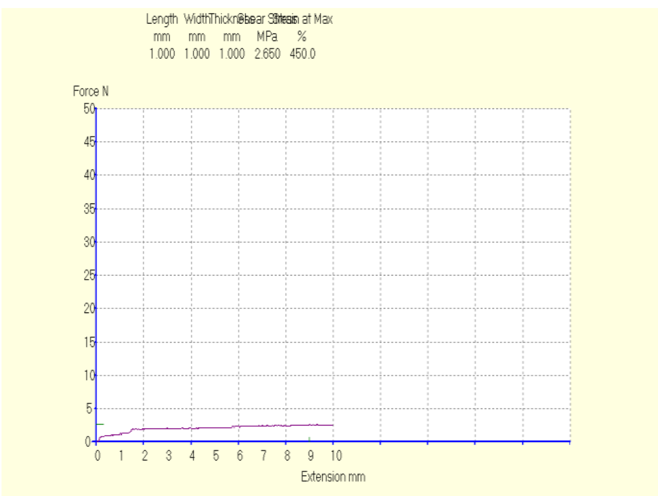


**Fig 4 -diagram drawn by Instron testing machine for each sample**

For simulation of the effect of the saliva we applied artificial saliva (NaCMC,tricalciom phosphate,sorbitol,KCl,NaCl,MgCl2,Na3PO4 ) with dropper during the sliding. The means and standard deviations of the friction force results for each group of wires were calculated and computed.Mann-Whitney test was used to statistically analyze the effect of coating status on the friction forces.

Statistical evaluation was performed by SPSS for Windows software (version 10.0, SPSS, Chicago, Ill). Descriptive statistics including means and standarddeviations values were calculated for each group. The Kolmogorov-Smirnov test was used to evaluate the normal distribution of variances. Comparisons of frictional forces were performed with Mann-Whitney test to test for differences between groups. . The level of significance was established at P _0.05.

## Results

The results of the friction force are displayed on anx-y graph, showing the magnitude of the frictionforce (in Newton's) during sliding of the wire for a 10-mm distance (Fig 4). The mean friction force and its standard deviationfor each group of different wires arecalculated. The mean frictional force was2.54±0.32 N in case group and 2.59±0.37N in control group. The result of Kolmogorov-Smirnov Test showed that mean frictional force as a variant has not normal distribution ($P < 0.05$)although case group showed 0.01 % (0.05 N) reduction in mean frictional forces; Mann-Whitney test showed that this change was not statistically significant.(P=0.62).(Table 1)

**Table 1. The results of Mann-Whitney test**

| group | N | Mean rank | Sum of rank | P value |
|---|---|---|---|---|
| ZO | 30 | 29.38 | 881.50 | |
| OO | 30 | 31.62 | 948.50 | 0.62 |
| Total | 60 | | | |

**Discussion**

One of the most important features of a frictiontesting apparatus is the accurate and similar positioningof each bracket–wire combination. To meet this requirement, new devices were specifically designed andbuilt for this study.

Reducing friction in the wire-bracket interface is believed to optimize the orthodontic force system during treatmentReduction of friction can mainly be achieved either by decreasing the friction coefficient of the bracket or wire materials or by decreasing the force of ligation acting on the wire[17], Manufacturing brackets with a low-friction-coefficient alloy[18],replacing the conventional twin tied brackets with single pair wing ligation (reducing the ligating force)[19], or using self-ligating spring clips might contribute to a significant reduction in the friction force.[20,21]

Nanoparticles are the particles with the size range of 100 nm or less. Their chemical and physical characteristics are substantially different from the same materials of the larger sizes. [22]

The mechanism by which the friction force is reduced after nanoparticles coating has been explained by Rapoportetal[23] and Cizaireetal[24].

At the first phase, when there is no angle between the bracket slot and the wire, that is, the bracket slot translates parallel to the wire, nanoparticles act as spacers decreasing the number of asperities which come into contact with each other leading in a decreased friction coefficient. As the angle grows between the slot and wire, the force increases at the edges of the slot and causes more friction resistance on the uncoated wire. At this point, some nanoparticles seem to exfoliate causing in the dry lubrication of the sliding process on the wires coated with nanoparticles. Furthermore, agglomerated nanoparticles slowly disintegrate when subjected to load application, releasing nanoparticles to the sheared interface. When the materials are made of stainless steel like the uncoated wires, the friction coefficient is more which increases through the time, possibly due to the tribochemical reactions leading to oxidation and adhesion between the rubbed surfaces.

When the nano-sheets subject to higher forces at the interface areas, the sliding take place between these thin sheets of the exfoliated nanoparticles at the interfaces, consequently reducing the coefficient of friction. Besides to this, ZnO nanoparticles act as a protection against the oxidation of the metal surfaces and decreases friction resistance consequently. [25]

Prasad etal. And Zabinskietal concluded that decreased coefficient of the friction after ZnO coatings is related to their nanostructure properties which increases lubricious characteristics of the surfaces and participate in their plastic deformation and reduced friction in turn.[26,27] Gotoet al.demonstrated that crystally preferred orientation of ZnO nanoparticles had significant effect on their low-frictional properties. [28]

Along with the hypothesis suggesting friction force reduction between orthodontic wires and brackets following their coating with nanoparticles, we evaluated the effect of zinc oxide nanoparticles coating of stainless steel wires on the reduction of the frictional forces in stainless steel wire-porcelain bracket combination .

The results showed a reduction in the friction resistance to sliding in the ZnO coated wires from 2.59±0.37N to 2.54±0.32 N.

In the present study although the mean frictional force decreased in coated wires (0.01 % reduction) but this change was not statistically significant. This result is in contrast to previous studies, whichshowed that coated wires produced asignificantly weaker friction force than did conventionalwires.

Redlichetal.studied the friction resistance of 0.019×0.025 orthodontic wires after coating with fullerene-like nanoparticles of tungsten

disulfide (WS2) and showed substantial reduction of friction forces after nanoparticles coatings.At an angle of 0 the reduction of friction was only 17%. As the angle grew to 5, the reduction rate grew to 46% and the 10 angle showed a 54% reduction of friction compared to the non-coated wires.[9]
Katz etal. showed coating with the fullerene-like WS2 nanoparticles significantly reduces arch wire friction with the possible alleviation of the adverse complications of the orthodontic treatments. [29] These studies have used fullerene-like nanoparticles of tungsten disulfide (WS2) which is somehow different from ZnO nanoparticles were used in the present study; although their effects to decrease friction resistance were similar. Also they used steel-steel interfaces as substrates whereas we examined steel-porcelain interface. Accordingly the result of the aforementioned studies can not be misinterpreted with our study.
Eskandarinejadet al. showed that ZnO nanoparticles coating on stainless steel wires can reduce the friction in sliding through stainless steel brackets. They did not simulate the effect of saliva on their experimental study.[14] Our study was the first laboratory experimental trial that addressed the frictional forces between coated wires and ceramic brackets. Ceramic brackets compared with stainless steel ones are condemned to have higher coefficient of friction [26] and increased surface roughness of porcelain brackets is considered as the main cause of this difference.[30] Also polycrystalline brackets have shown increased surface irregularity under electron microscope. [31]
The importance of comparative friction force studiesof new brackets is that they give clinicians independentdata within the limits of in vitro models. However, these in vitro results are not relevant for clinicalsituations. We recommend extending the scope ofsimilar studies, testing new archwires, and simulatingsaliva in in-vitro wet conditions.One advantage of ZnO particles compared to WS2 is its biocompatibility and safety to human health.[32] The friction coefficient of the compact zinc oxide on the higher temperatures is about 0.65. Zinc oxide is not able to create a lubricious surface in the powder or compact disc forms; however, nanostructure zinc oxide is capable to develop lubricious surfaces with a friction coefficient of 0.2.[33]It seems that nanoparticles coatings on the brackets and wires of stainless steel lead to the reduced frictional resistance due to the removal of corrosion factors too.
In the present study, we calculated the mean frictional forces. Some argued that as the movement occurs when the applied forces overcome the static friction resistance; thereby calculation of static friction would be more important than kinetic friction because orthodontic sliding of a tooth (bracket) in an archwire is not a continuous or constant motion. As a result, tooth movement does not resemble the classical pattern of an object sliding on another, thereby from the clinical point of view, overcoming the static friction force between the bracket and the wire is a prerequisite for tooth movement.[34] Some others suggested the study of kinetic frictional force in the tooth sliding movements.[35-37] In addition overcoming static friction cannot lead to tooth movements and it is the biologic resistance of periodontium that plays an important role in this movement without any distinct values. Furthermore, it seems that measurement of static and kinetic friction separately is not practical clinically. Regarding the above mentioned arguments, the mean frictional force was measured in the present study.
Due to the positive effects of nanoparticles coatings in the decreased frictional forces between orthodontic wires and brackets; the coatings can be applied to other orthodontic appliances.

Because the increased friction is contributed to higher surface roughness of ceramic brackets, coating the ceramic surface instead of the wire should be tried. With the improvement of coating methods and their approval for use in the oral cavity, the friction during orthodontic treatments could be significantly decreased, resulting in the better anchorage control with the consequent reduced treatment time and risk of root resorption. However, more studies are required to assess nanoparticles cellular toxicity or their effects on different organs in order to approve their safety.

**Conclusion**

1. Following ZnO nanoparticles coating on the wire, the friction force between ceramic brackets and wires did not decrease significantly.
2. Further studies are required, especially with coating nanoparticles on ceramic brackets.

**References**

1-Shames IH. Engineering mechanics: Statics and dynamics.Upper Saddle River, N.J: Prentice Hall;1997:100.
2-Halliday D, Resnick R. Fundamentals of physics. New York: Wiley;1988:156.
3-Nikolai RJ. Bioengineering analysis of orthodontic mechanics. Philadelphia: Lea & Febiger;1985: 131-55.
4-Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and arch wires. Am J Orthod Dentofac Orthop 1991; 100:513-22.
5-Tidy DC. Frictional forces in fixed appliances. Am J Orthod Dentofac Orthop 1989;96:249-54.
6-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;4:686-90.
7-Thorstenson GA, Kusy RP. Resistance to sliding of self-ligating brackets versus conventional stainless steel twin brackets with second-order angulation in the dry and wet (saliva) states. Am J Ortod Dentofac Orthop 2001;120:361-70.
8-Cash A, Curtis R, Garrigia-Majo D, McDonald F. A comparative studyof the static and kinetic frictional resistance of Titanium Molybdenum alloy archwire in stainless steel bracket. Eur J Orthod 2004;26:105-11.
9-Redlich M, Katz A, Rapoport L, Wagner HD, Feldman Y, Tenne R. Improved orthodontic stainless steel wires coated with inorganic fullerene-like nanoparticles of WS2 impregnated in electroless nickel-phosphorous film. Dent Mater 2008;24:1640-6.
10-Tenne R, Margulis L, Genut M, Hodes G. Polyhedral and cylindrrcal structurs of WS2. Nature 1992;360:444-5.
11-Feldman Y, Wasserman E, Srolovitz DJ, Tenne R. High rate- gw phase growth of MOS2 nested inorgaric fullerenes and nanotubes. Science 1995;267:222-5.
12-Wei S, Shao T, Ding P. Study of CNx film on 316L stainless steel for orthodontic application. Diam Relate Mater 2010;19:648-56.
13-Goto M, Kasahara A, Tosa M. Reduction in frictional force of ZnO coatings in a vacuum. Jpn J Applied Phys 2008;47:8914-6.
14-Eskandarinejad.the effect of ZnO nanoparticles deposition for friction reduction on orthodontic wires .[thesis].Tabriz,Iran:Tabriz University of Medical Sciences ;2012,49-57.
15-Drummond C, Israelachvili J. Dynamic phase transitions in confined lubricant fluids under shear. Phys Rev E Stat Nonlin Soft Matter Phys 2001;63:150-6.
16-Angolkar PV, Kapila S, Duncanson MG Jr, Nanda RS.Evaluation of friction between ceramic brackets and orthodontic wires of

four alloys .Am J Orthod Dentofac Orthop 1990;98:499-506.
17-Kapur R, Sinha PK, Nanda RS. Comparison of frictional resistancein titanium and stainless steel brackets. Am J Orthod Dentofacial Orthop 1999;116:271-4.
18-Meling TR, Odegaard J, Holthe K, Segner D. The effect offriction on the bending stiffness of orthodontic beams: a theoreticaland in vitro study. Am J Orthod Dentofac Orthop1997;112:41-9.
19-Suyama H, Higashi K, Nakata S, Nakasima A. New edgewisebracket with rounded slot and variable ligation. J Clin Orthod1995;6:398-402.
20-Berger JL. The influence of the SPEED bracket’s self-ligatingdesign on force levels in tooth movement: a comparative in vitrostudy. Am J Orthod Dentofac Orthop 1990;97:219-28.
21-Shivapuja PK, Berger JL. A comparative study of conventionalligation and self-ligation bracket systems. Am J Orthod Dentofacial Orthop 1994;106:472-80.
22-Rakhshani AE, Thomas S. Characteristics of aligned ZnO nanorods grown on stainless-steel foil by successive chemical solution deposition. Phys Stat Sol, 2008;205:1615-8.
23-Rapoport L, Leshchinsky V, Lapsker I, Volovic YU, Nepomnyashchy O, Lvovski M, et al. Tribological properties of WS2 nanoparticles under mixed lubrication. Wear 2003;255:785–93.
24-Cizaire L, Vacher B, Le-Mogne T, Martin JM, Rapoport L, Margolin A et al. Mechanisms of ultra-low friction by hollow inorganic fullerene-like MoS2 nanoparticles. Surf Coat Technol 2002;160:282–7
25-Friedman H, Eidelman O, Feldman Y, Moshkovic A, Perfiliev V, Rapoport L, et al. Fabrication of self-lubricating cobalt coatings on metal surfaces. Nanotech 2007;18:115703.
26-Prasad SV, Zabinski JS. Tribological behavior of nanocrystalline zinc oxide films. Wear 1997;203:498-506.
27-Zabinski JS, Sanders JH, Nainaparampil J, Prasad SV. Lubrication using a microstructurally engineered oxide: performance and mechanisms. Tribol Lett 2000; 8:103-16.
28-Goto M, Kasahara A, Tosa M. Low-friction coatings of zinc oxide synthesized by optimization of crystal preferred orientation. Tribol Lett 2011;43:155-62.
29-Katz A, Redlich M, Rapoport L, Wagner HD, Tenne R. Self-lubricating coatings containing fullerene-like WS2 nanoparticles for orthodontic wires and other possible medical applications. Tribol Lette 2006;21:135-9.
30-Nanda R . Biomechanics in Clinical Orthodontics . Philadelhpia Pennsylvania WB.Saunders company;1997: 197.
31-Omana HM ,Moore RN ,Bagby MD. Frictional properties of metal and ceramic brackets .J Clin Orthod 1992;26:425-32.
32-Schilling K, Bradford B, Castelli D, Dufore E, Nash JF, Pape W, et al. Human safety review of “nano” titanium dioxide and zinc oxide. Photochem Photobiol Sci 2010;9:495-509.
33-Zabinski JS, Corneille J, Prasad SV. Lubricious Zinc oxide films: synthesis, characterization and tribologicalbehavior. J Mater Sci 1997;32:5313-9.
34-Redlich M, Mayer Y, Harari D, Lewinstein I. In vitro study of frictional forces during sliding mechanics of ‘‘reduced-friction’’ brackets. Am J Orthod Dentofacl Orthop 2003;124:69-73.
35-Sunil K, Padmaraj V, Angolkar MG, Duncanson JR, Nanda RS. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. Am J Orthod Dentofac Orthop 1990;98:117-26.
36-Berger JL. The influence of SPEED brackets self ligatingdesign on force level in tooth movement. Am J Orthod Dentofacial Orthop 1990;97:219-28.
37-Kusy RP, Whitley JD. Effect of sliding velocity on frictional coefficient of archwires.J Dent Res 1989;68:275-83.