Friction reduction during sliding in different angles with Zno nanoparticles deposition on orthodontic wires

Mojghan Kachoei [a], Faranak Eskandarinejad [b], Mahsa Eskandarinejad [c]

Abstract

Aim: Friction accompanies all sliding techniques. Sliding is in the manner of tipping and uprighting with increasing angle between bracket and wire. Recently, wire coating with the different nanoparticles has been proposed to decrease the frictional forces. The present study was done to coat the stainless steel wires with the ZnO nanoparticles and determine the effect of this coating on friction reduction during different angle between the wires and brackets.

Materials and Methods: Eighty pieces of 0.016 stainless steel wires with and without zinc oxide nanoparticles were used in 80 pieces of orthodontic brackets (0.018). The coated wires analyzed by the SEM and XRD observations. Friction between the wires and orthodontic brackets at 0,5,10 degree angle were calculated using universal testing machine. Two and three group comparisons were done by means of Student t and one-way ANOVA respectively and Tukey post hoc test was used to assess the paired comparisons.

Results: Frictional values were significantly increased with the increased angles between the wire and bracket. the increased friction force from 0 to 10 degree in uncoated wires were Statistically more significant than increased friction force from 0 to 10 degree in coated wires ($p<0.005$)

Conclusion: considering the positive effects of zinc oxide nanoparticles coating in decreasing frictional forces, they might offer a novel opportunity to significantly reduce friction during sliding and consequent better anchorage control, reduced risk of root resorption.

Key words: Zinc oxide nanoparticles, Friction, Orthodontic wires, Brackets.

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Frictional force between the bracket and wire is unavoidable in the sliding procedure with higher forces requiring to overcome it which faces the anchorage control with some risks in turns.[1-4]

[a]Associate professor, Department of orthodontics,school of dentistry,Tabriz university of medical science
[b] Post graduate student, Department of orthodontics,school of dentistry,Tabriz university of medical science
[c].Assistant professor, Department of endodontics,school of dentistry,Tabriz university of medical science

Corresponding author:
Dr Mojghan Kachoei,
E-mail: drkachoei@gmail.com

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 without any linear pattern. 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, subjects to notching and plastic deformation slowly; all these procedures lead to the prohibition of tooth continuous movements with numerous stops to be occurring during the tooth translation finally.6 Overcoming this obstacle requires excessive orthodontic forces about 40%-60%. At the same time, the increased forces enhance the anchorage loss risk which is a major problem in the orthodontics treatments. Tooth root resorption is another main disadvantage of increased load values. [7, 8]

Some procedures have been developed to overcome this impediment such as using wires of the different metals, shapes and sizes, as well as application of external oral forces or using temporary implants.[8] Furthermore, the use of nanoparticles invented in the 1990s, has been stressed 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 or brackets must be coated with the nanoparticles.[9] Redlich et al. coated 0.019×0.025 orthodontic wires with inorganic fullerene-like nanoparticles of tungsten disulfide (WS2) and showed significant reduced frictional forces on the wires.[9] Furthermore, the stainless steel orthodontic wires were subjected to significant decreased frictional forces when coated with the nanoparticles of CNx as suggested by Wei et al [12]. Goto et al. demonstrated a reduction in the frictional coefficient of the ZnO coated stainless steel substrate in the vacuum.[13]

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 leading in 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 nano-particles to decrease the frictional forces and allow the sliding to occur. [9-11,14]

Obviously, future clinical use of the coated wires will be subjected to the safe biocompatibility tests according to accepted procedures. Considering possible toxology of WS2, new self-lubricating coatings in which metals other than WS2 were used is needed to be prepared and analyzed.

The objective of the present study was to assess the effect of zinc oxide spherical nanoparticle coatings on the reduction of frictional forces in sliding tooth movement.

Methods and Materials

In this laboratory experimental trial, 40 number of orthodontic wires of 0.016 (American orthodontics, USA)were used with and without ZnO nanoparticles coating. The studied devices included 40 number of stainless steel brackets of the upper right centrals in 0.018 standard system (Ultratrimm, Dentaurum, Germany), 40 number of 0.016 stainless steel (SS) straight wires (American orthodontics ,USA) with and without spherical ZnO nanoparticles coating . Furthermore, Universal Testing Machine (Hunsfield Test Equipment, H5K Model; England) was used to make pulling and sliding movements between the wires and brackets.

For coating zinc oxide nanoparticle 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 gr 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 following by the immersion of the wires into the solution separately.16, 17 (Figure 1). SEM images of the wires approved ZnO nanoparticles coating in this method (Figure 2).

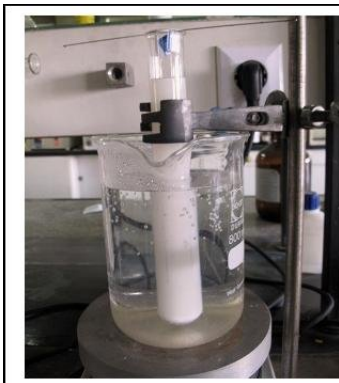

Figure 1: Soaking the wires into the solution for nanoparticles coating

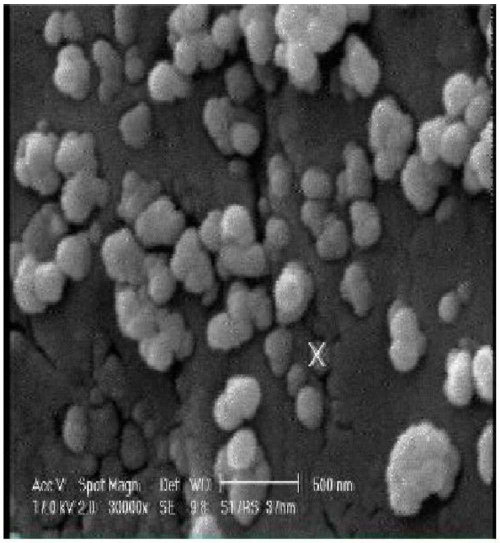

Figure 2: SEM of coated wire with zinc oxide

The friction force calculations during the sliding procedure were performed after nanoparticles coatings and the wires preparations. Central tooth brackets were bonded using a cyanoacrylate adhesive to an aluminum plate with a special bracket-mounting device in a fixed position. Then, the aluminum plate was fastened with the screws to a notch created on a special device designed for the bracket carrying. It was attached to the base of Universal Testing Machine then. In order to make similar conditions for all specimens, the brackets were changed after each wire sliding. The aluminum plate was positioned in three different notches angulated at 0°, 5° and 10° to the long axis of the device using a special screw holding instrument for the simulation of the second order bends.[17]

Orthodontic wires were connected to the brackets by means of elastomeric module (Dentaurum) . The upper end of the wire was inserted into a tension load cell of the universal testing machine, and a 150 gr weight was connected to the lower end of the wire. The wires were then drawn through the bracket at the speed of 0.5 mm/sec for 25 seconds while the frictional forces were calculated by means of universal testing machine (Figure 3) . [18] All friction forces measured at this study were of kinetic type as no calculations were done at the basic time but after 0.1 second frictional value were calculated.17

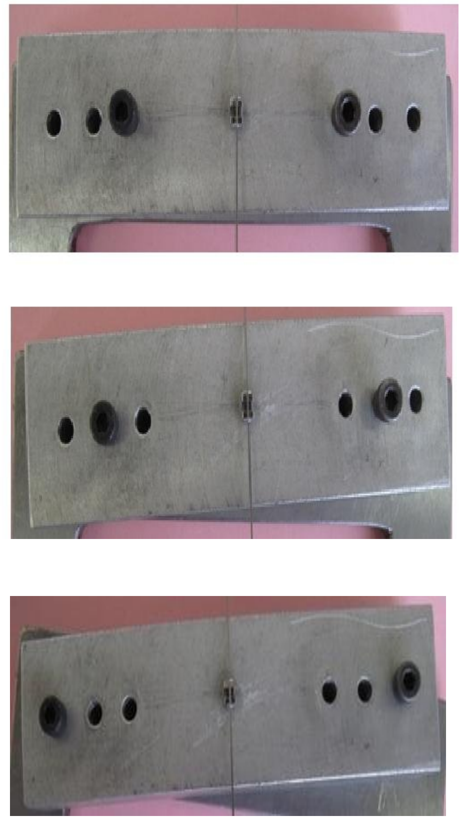

Figure 3: Friction measurements by means of Universal Testing Machine at 0 degree angle

Figure 4: Friction measurements by means of Universal Testing Machine at 5 degree angle

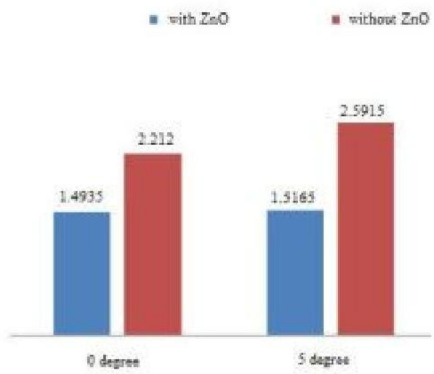

Figure 5: Friction measurements by means of Universal Testing Machine at 10 degree angle

Figure 6: Mean friction force of 0.016 wire at 0,5,10 degree

The mean and standard deviation of friction forces were computed. Two and three group comparisons were done by means of Student t and one-way ANOVA respectively as well as Tukey post hoc test was used to assess the paired comparisons.

Results

On 0.016 wires, mean friction force was estimated to be 1.5668±0.107 N and 2.56±0.3401 N for the coated and uncoated wires in all angles of the brackets and wires; suggesting significant reductions of the friction(39%) following ZnO nanoparticles coating (Student t: $p<0.0001$).

Significant reduction of the friction force by 32.48% was observed at 0° for the ZnO coated versus uncoated wires (Student t: $p<0.0001$). At the 5° angle, friction force on the coated versus uncoated wires show significant reduction for 41.48% (Student t: $p<0.0001$). At the 10° angle, a significant decrease on the friction force by 41.23% was shown for coated versus uncoated wires (Student t: $p<0.0001$) too. (Figure 4)

Table 1: Mean, standard deviation and standard error of the friction forces on different degree

At combined coated and uncoated wires, the friction force was 1.8528±0.427 at the 0° angle, 2.054±0.548 N at 5° angle, and 2.2835±0.61 N at 10° angle. Statistically significant increases were observed in the friction force with the increasing angles between the brackets and wires (one-way ANOVA: $p<0.002$). As shown by Tukey multiple comparisons test, the friction force was differently reported at 0° and 10° angles ($p<0.001$) while it was not so between 0° and 5° angles ($p=0.22$) or 5° and 10° angles ($p=0.14$).

At uncoated wires, the friction force was 2.212±0.319at the 0° angle, and 2.876±0.077 N at 10° angle. At coated wires, the friction force was 1.493±0.031at the 0° angle, and 1.690±0.136 N at 10° angle. the increased friction force from 0 to 10 degree in uncoated wires were Statistically more significant than increased friction force from 0 to 10 degree in coated wires ($p<0.005$)

Figure 7: mean friction force of 0.016 coated and uncoated wire at 0,5,10 degree

Discussion

Nanoparticles of metal dichalcogenide discovered in the early 90s are known to serve as solid lubricants under various conditions, the plastic deformation in nano-crystalline metals could be achieved mainly by grain boundary sliding and a minor contribution from dislocation activity in the grains.18

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 coatings on the decrease of the frictional forces.

The results showed a substantial reduction in the friction resistance to sliding in the ZnO coated wires at all studied angles .the friction force between 0.016 wire and slot of 0.018 bracket system was significantly decreased to 32.48%, 41.48% and 41.23% at 0°, 5° and 10° angles respectively following ZnO nanoparticles coatings.

the mean friction forces of on 0.016 wires show 39% reduction after coating that suggested a substantial reduction in the friction resistance after ZnO coatings. During increasing angle from 0 degree to 10 degree, in uncoated group friction value increased more than the uncoated group. The mechanism by which the friction force is reduced after nanoparticles coating has been explained by Rapoport et al. 19 and Cizaire et al. 20

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, which only occurs when the nanoparticles release from the coating surfaces by electroless procedure and transfer to the opposing metal (bracket).9-11,14

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, But in coated wire some nanoparticles seem to exfoliate and slowly disintegrate when subjected to load application, releasing nanoparticles to the sheared interface causing solid lubrication effect .

Furthermore, 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.9

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 9,that is obviously observed in coated group during increased angle from 0 to 10 degree but not in uncoated group.

Besides to this, ZnO nanoparticles act as a protection against the oxidation of the metal surfaces and decreases friction resistance consequently.21

Prasad et al. and Zabinski et al. 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.22,23 Goto et al. demonstrated that crystally preferred orientation of ZnO nanoparticles had significant effect on their low-frictional properties using x-ray diffraction spectroscopy.24

Redlich et al. studied the friction resistance of 0.019×0.025 orthodontic wires after coating with fullerene-like nanoparticles of tungsten disulfide (WS_2) 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 wire which is somehow similar to our findings.9 Katz et al. showed coating with the fullerene-like WS_2 nanoparticles significantly reduces arch wire friction with the possible alleviation of the adverse complications of the orthodontic treatments.25 These studies were done using fullerene-like nanoparticles of tungsten disulfide (WS_2) which is somehow different from ZnO nanoparticles were used in the present study; although their effects to decrease friction resistance were similar. One advantage of ZnO particles compared to WS2 is its biocompatibility and safety to human health.26

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. 27 It seems that nanoparticle coatings on the brackets and wires of stainless steel lead to the reduced frictional resistance due to the removal of corrosion factors too.

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 and materials such as conventional brackets of 0.022 system and self-ligating systems and to initial treatment of 0.019×0.025 stainless steel wire and flexible wires like Ni-Ti arches. 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 the body different organs in order to approve their safety.

Conclusion

Following ZnO nanoparticles coating, the friction force between brackets and wires significantly decreased. Due to the positive effects of zinc oxide nanoparticles coating to decrease the friction forces, these nanoparticles might offer a novel opportunity to significantly reduce friction during tooth movement and consequent better anchorage control, reduced treatment time and risk of root resorption.

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