https://doi.org/10.48047/AFJBS.6.Si4.2024.859-870

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Effect of Zirconium Dioxide Nanoparticles Coating of Orthodontic Appliance on The Rate of Maxillary Canine Retraction (Randomized Control Study)

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Article History

Volume 6, Issue Si4, 2024
Received: 25 May 2024
Accepted: 15 June 2024
doi:
10.48047/AFJBS.6.Si4.2024.859-8**70**

Abstract
Background: Owing to the drawbacks that occurs due to the long periods of orthodontic treatment, such as the development of white spot lesions, root resorption, and periodontal disease, accelerated orthodontic tooth movement is a paramount objective of the contemporary orthodontic community. Major orthodontics industries invest in new innovations that claim that they reduce the resistance to friction between orthodontic archwires and brackets, thus the treatment duration. One of the methods to improve archwire properties and reduce the resistance to friction during sliding mechanics is to coat the archwire with different materials. The introduction of nanotechnology in the medical and dental industries allows the use of different types of materials in a manner that allows manufacturers to coat wires with different materials to obtain different properties.
The aim of the studywas to determine whether zirconium dioxide nanoparticles coated orthodontic appliances demonstrate a higher rate of tooth movement during a single canine retraction procedure than a non-coated orthodontic appliance.
Material & method: This study was a split- mouth randomized control trial. It was carried on twenty-one patient with forty-two canines were retracted. They were randomly divided into three cohorts; each cohort contained a side that was randomly selected as either the control or study side. Cohort A: the study was (coated wire and coated brackets). Cohort B: the study side was (coated wire and uncoated brackets). Cohort C: the study side was (uncoated wire and coated brackets). All patients were fitted in a selective criterion. Digital scans were taken at each visit, and superimposition was performed using Medit Design® software. The rate of canine retraction per visit was measured.
Results: (Cohort A) showed a statistically significant difference between (control) and (study) sides where the highest mean value was found in (control) side. (Cohort B): There was a significant difference between

(control) and (study) sides with highest mean value was found in (study) side. (Cohort C): There was a significant difference between (control) and (study) groups with the highest mean value was found in (control) side. There was a statistically significant difference between (Cohort A), (Cohort B) and (Cohort C) (*p value* <0.001). A statistically significant difference was found between (Cohort A) and each of (Cohort B and C) (*p value* =0.001) and (*p value* <0.001) respectively. In addition, a statistically significant difference was found between (Cohort B) and (Cohort C) (*p value* <0.001). The highest mean value was found in (Cohort B), while the lowest mean value was found in (Cohort A).

Conclusion: These results suggest that zirconia coated nickel titanium orthodontic archwires increased the rate of canine retraction compared to the non-coated appliance. Unexpectedly, in clinical practice, coating both archwires and brackets acted negatively and reduced the rate of canine retraction.

Key words: orthodontic wire coating, zirconium dioxide, friction, frictional resistance, nanoparticles, nanotechnology

Conflict of Interest declaration: The authors declare that they have NO affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Introduction

Regarding the duration and the length of orthodontic treatment, there is no agreement in the literature. According to a recent systematic study, fixed appliance treatment takes an average of 19.9 months. (1) But there was a lot of diversity between the studies, and there was no evaluation of the end results quality of the treatment. However, it is consented that if the treatment period increases, risks and side effects associated with orthodontic appliancesincreases, such as root resorption, white spots, carious lesions, and gingival inflammation. (2) Additionally, using fixed appliances affect patient's quality of life and self-esteem because they can cause discomfort and problems with their daily routine. (3)

Accordingly accelerating orthodontic tooth movement to shorten the treatment period is mandatory, not only to decrease the hazards that may occur during the long treatment period, but also, maintain adult patients' motivation throughout the treatment till the finishing stage. (4) As a result, researchers have investigated if it is achievable to move the teeth more quickly than with traditional techniques either by changing the application materials, using different design or using more aggressive methods such as surgical assisted orthodontic tooth movement or using chemicals and medications such as Prostaglandins (PGs), hormones or vitamins either injected locally or delivered systemically. (5)

Also attempts to decrease orthodontic friction is another method for more efficient orthodontic tooth movement. Orthodontic friction involves interaction between the bracket slot, wire, and ligature system. (6) So, minimizing friction is one of the main goals for rapid orthodontic tooth movement. Various approaches have been developed to minimize frictional resistance, including the development of different mechanical protocols, different appliance designs, and different ligation methods, including coating and altering the surface of orthodontic metallic wires using various procedures and materials.(7) One of the most recently introduced technologies in the medical field which can depend upon is nanotechnology.(8)

Altering wires surfaces with coating material that has superior property is a method to reduce frictional resistance. This tactic used to strengthen the mechanical and biological qualities of some materials used in orthodontics by applying coatings to the surface of orthodontic archwires with various methods and materials, as well as by altering their surface.Depending on its intended use, coatings come in a variety of forms. In order to influence the surface features of orthodontic archwires- such as surface roughness, thickness, mechanical and frictional qualities, corrosiveness, bacterial adherence, and coating stability- coating is applied. Various materials and coating methods have been employed to improve surface characteristics. (9)Aiming to improve the coating ability of various materials, research is being done to identify suitable materials and methodologies in response to several coating issues, including delamination and coating wear. One of these methods that is used to improve wire materials coating is nanotechnology. (10)

Materials classified as nanoparticles (NPs) when its particles size are below 100 nm in a minimum of one dimension. (11) Nanomaterials (NPs) distinct from other materials behavior in that they have a substantially higher surface area per unit mass than larger particles. Therefore, changes regarding mechanical, physical and chemical properties are included. (12)It has been claimed that over 3500 dental materials contain nanoparticles, which can be from metals, polymers, or ceramics. (13) Noble metals like gold (Au), copper (Cu), platinum (P), and silver (Ag) as well as metal oxide nanoparticles (NPs) like magnesium oxide (MgO), iron oxide (FeO), zinc oxide (ZnO), titanium dioxide (TiO2), silicon dioxide (SiO2), and zirconium dioxide (ZrO2) are the most often used nanoparticles in dentistry and orthodontics due to their broad spectrum bactericidal properties. (14), (15)Application of surface nano coatings to orthodontic brackets, archwires, and aligners has become progressively relevant in recent years. These coatings function as a dry lubricant, eliminating the requirement for liquid lubrication and effectively reducing friction between two sliding surfaces. Furthermore, as was discussed, nanoparticles reduce friction by producing a smooth surface. (16)

It is necessary to conduct long-term clinical investigations to assess the integrity of various nanocoating types and to ascertain whether the reduced friction observed in vitro tests has any practical application. Accordingly, this study was conducted.

Materials and methods:

I) Materials

Wire used: Wire customization was required to fit into research objectives as a split-mouth randomized control clinical trial requiring a half coated and half non coated one segment archwire. Therefore, two different parts of the arch wire were constructed by joining two wires (one coated and the other non-coated). Laser welding is one of the methods used for joining different alloys. It was found that there was no significant difference in the deflection load of the welded archwires, which could be used in clinical practice with no significant effect on the mechanical load distribution between inter-bracket distances.(17) Regarding the archwire size and material, Stainless steel 0.0020 inch commercially available arch wire was used (Dentaurum®, Germany).

Brackets used: All patients were fitted withRothprescription maxillary and mandibular preadjusted edgewise fixed appliances.

Nanoparticlescoating: There are various methods for coating different surfaces with nanoparticles materials. The sol–gel method was used in this study. It is a chemical method that allows the synthesis of glass and ceramic materials at significantly low temperatures and with diverse shapes. Sol-gel processes are suitable for the synthesis of oxide nanoparticles and composite nano-powders. In this method, a solution system is transformed from a liquid sol into a solid gel, and a dry gel is obtained. It was found that, commercially available orthodontic wires can be successfully coated using the sol-gel thin film dip coating method also it was proved that coating commercially available orthodontic wires with nanoparticles improves their surface topography. In that trial, Zirconium Dioxide Nanoparticles were used as the material of choice for examination, as it is well known in dental practice to have superior physical and mechanical properties. [18]

Patients selection: This study was conducted in orthodontic patients with malocclusion who required extraction of maxillary premolars and distalization of canines (i.e., Cl II cases). Patients were recruited according to the inclusion and exclusion criteria from the outpatient clinic of the Orthodontic Department of the Faculty of Dental Medicine, Minia University. Informed consent forms were obtained from all participants or their legal guardians and were approved by the Scientific Research Ethics Committee of the Faculty of Dentistry, Minya University, registered no (RHDIRB2017122004).

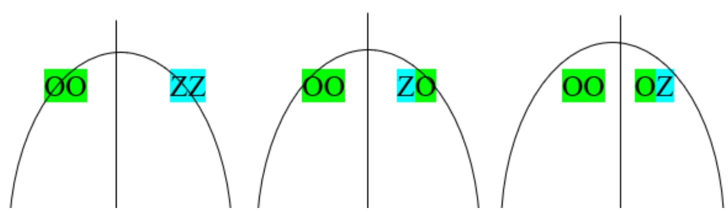
***Inclusion* criteria:** All patients were in permanent dentition. The degree of crowding ranged from (0 mm) crowding to minimal (≤ 4 mm). None of the Patients had received any previous orthodontic or major periodontal treatment and showed no to minimal bone loss. No systemic diseases or routinely used drugs. Not smoking with good oral hygiene.

Exclusion criteria: Severe skeletal discrepancy.Long-term use of drugs such as anti-inflammatory drugs, systemic corticosteroids, and antibiotics.Patients with anysystemic disease.

Randomization tool: Selection was performed using a random selection website (www.randomizer.org), which is a free resource for researchers to generate random selections. To avoid selection bias, each patient was requested to select random code shuffled previously using a software application, and the codes were inserted in a previous excel sheet that allocated the patient in which cohort and which side would be the study or the control.

Blinding: This study did not allow the clinicians or patients to be blinded. However, blinding was limited to the statistical outcome assessment.

Grouping: The control and study groups were monitored according to random selection. The patients were divided into three cohorts: Cohort A, Cohort B, and Cohort C, as depicted in the illustration.



OO (uncoated wire and uncoated bracket), ZZ (coated wire and coated bracket), ZO (coated wire and uncoated bracket), OZ (uncoated wire and coated bracket)

II) Methods:

All patients were fitted with a preadjusted edgewise fixed orthodontic appliance with Rothprescription (AO American Orthodontics Mini Master®). Archwire-sized sequences were used as the regular sequences that were used in most cases. Each archwire will be used for 4 weeks, but some cases may require more than 4 weeks of a specific wire in sequence for the relief of crowding. After four weeks of using the main archwire (0.020-inch stainless steel), the retraction phase was initiated using equal forces on both sides (right and left). Retraction force: NiTi coil spring for space closure with a force gauged (50 gm- 500 gm) each visit to 150 gm /side to produce a constant force with minimal degradation. [19] A NiTi closed coil was used on the other side, which was connected to the canine and first molar using a 0.009-inch ligature wire. [19]

Point considered: Extraction performed after initial alignment, as all cases were selected with minimal crowding (≤ 4 mm). In addition, extraction was performed for a 6 weeks period pause before starting retraction, with the dead coil placed exactly at the inter-bracket distance of the extraction space. This was to exclude the effect of regional acceleratory phenomenon (RAP). [20] Reduce the variables that might affect resultant tooth movement.

Method of anchorage: Nance appliance with bands on the upper second permanent molars was used to provide maximum anchorage during the single canine retraction phase. Anterior bite planes bilaterally on the central and lateral incisors. The choice of this appliance for anchorage management allows appliance removal at each visit and complete registration of the rugae area for an accurate and reproducible superimposition. Anterior bite plane construction was used to remove any bite interference that might occur during canine retraction, which might interfere with the rate of canine retraction.

Assessment: Dental stone models was taken before canine retraction and at 1-month intervals from retraction (days 0, 30, 60, 90, and 120). The models were digitized as three-dimensional models. The changes were measured on the superimposed models. All superimpositions were performed using the Medit Design software version 3.1.0.After importing the T0 and T1 (STL) files in the Medit Design software, the superimposition reference area was selected on the T0 model (a small area of the palate including the medial 2/3 of the third rugae and the area 5 mm dorsal to them) [21]. Canines were selected as teeth for which movement from T0 to T1 was assessed.

Statistical analysis: Mean and standard deviation values were calculated for each group in each test. Data were analyzed for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests, and data showed a parametric (normal) distribution. One-way ANOVA followed by Tukey's post-hoc test was used to compare more than two groups in unrelated samples. A paired-sample t-test was used to compare more than two groups in the related samples. The significance level was set at P ≤ 0.05. Statistical analysis was performed using IBM SPSS Statistics Version 20 for Windows.

Results

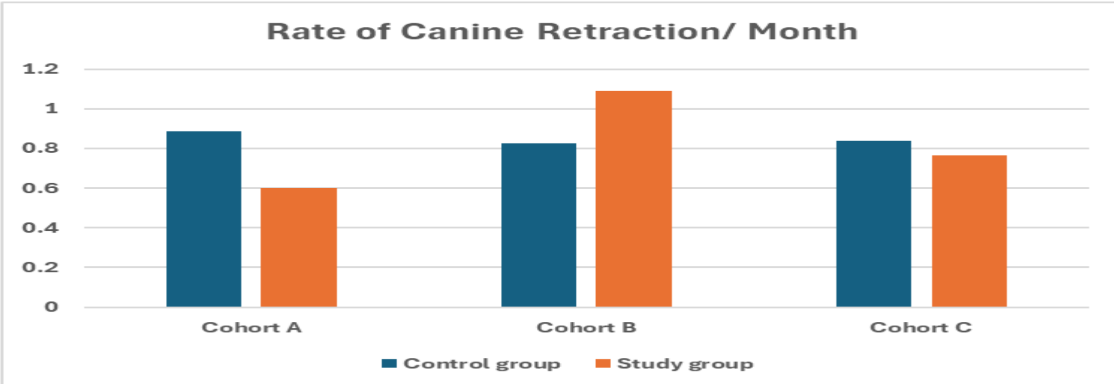
I) Rate of canine retraction per month (relation between control and study groups)

Cohort A: There was a significant difference between (control) and (study) groups (*p value*<0.001). The highest mean value was found in (control) group, whereas the lowest mean value was found in (study) group.**Cohort B:** There was a significant difference between (control) and (study) groups (*p value*<0.001). The highest mean value was found in (study) group, whereas the lowest mean value was found in (control) group. **Cohort C:** There was a significant difference between (control) and (study) groups (*p value*<0.001). The highest mean value was found in (control) group, whereas the lowest mean value was found in (study) group.

Variables	Rate of Canine Retraction/ Month					
	Cohort A		Cohort B		Cohort C	
	Mean	SD	Mean	SD	Mean	SD
Control group	0.886	0.069	0.827	0.043	0.839	0.055
Study group	0.601	0.068	1.091	0.071	0.767	0.060

p-value	**<0.001***	**<0.001***	**<0.001***

Mean and standard deviation (SD) values of the rate of canine retraction/month of differentgroups. * Significant difference (*p value*<0.05).



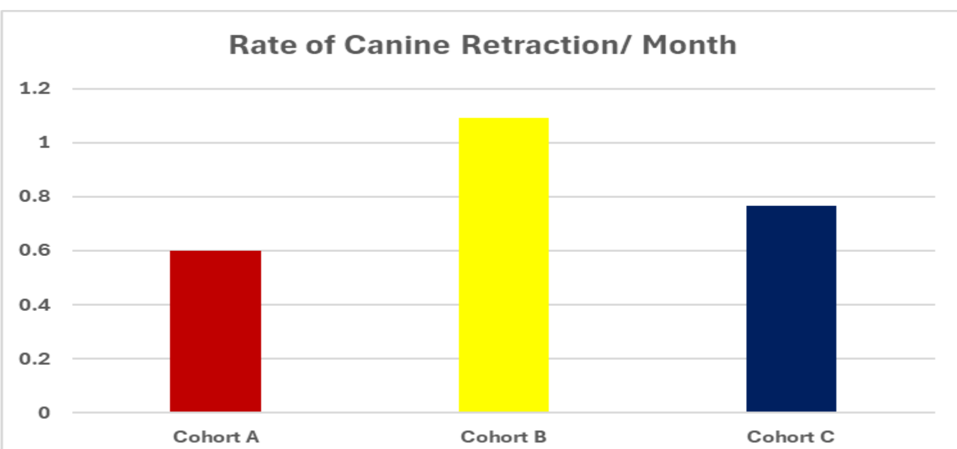
Bar chart representing Rate of Canine Retraction/ Month of different groups

II) <u>Relation between groups:</u>

<u>Study groups:</u>There was a statistically significant difference between (cohort A), (cohort B) and (cohort C) groups where (*p value*<0.001). A statistically significant difference was found between (cohort A), (cohort B) and (cohort C) groups where (*p value* =0.001) and (*p value*<0.001, respectively). In addition, a statistically significant difference was found between (cohort B) and (cohort C) groups where (*p value*<0.001). The highest mean value was found in (Cohort B) group, while the lowest mean value was found in (cohort A).

Variables	**Rate of Canine Retraction/ Month**	
	Study groups	
	Mean	**SD**
Cohort A	0.601 ^{c}	0.068
Cohort B	1.091 ^{a}	0.071
Cohort C	0.767 ^{b}	0.060
p-value	**<0.001***	

Mean and standard deviation (SD) values of the rate of canine retraction/month of different groups. Means with different lowercase letters in the same column are significantly different. * Significant difference (*p value*<0.05).



Bar chart representing Rate of Canine Retraction/ Month for different groups

Discussion:

Our research question was: "Does ceramic nano-particles coating improves the clinical performance of orthodontic archwires and orthodontic brackets?". Therefore, the aim of this in-vivo randomized clinical trial was to conduct a split-mouth study and to measure the rate of canine retraction and comparing canine retraction rate in different cohorts of patient. The clinical importance of ceramic nanoparticle wire coating in our practice was investigated by this study. The null hypothesis (H_0) of the of the research was: "coating orthodontic archwires and orthodontics brackets with zirconium dioxide nanoparticles will not affect canine retraction rate". The alternative hypothesis (H_a) was "coating orthodontic archwires and orthodontics brackets with zirconium dioxide nanoparticles will increase rate of canine retraction".

Coating orthodontic archwires enhances archwire qualities, including surface topography, frictional resistance, tarnish and corrosion resistance, antibacterial properties, and esthetics of the wires. There are many studies focusing on novel coatings to cover orthodontic archwires and brackets with various materials. In our research zirconium dioxide was the material of choice. Zirconium dioxide, sometimes referred as zirconia, is a white crystallin particles with great thermal and mechanical properties. It displayed excellent mechanical, and aesthetic qualities together with remarkable biocompatibility. It got popularized in all dental fields, such as in manufacturing of orthodontic brackets, implant abutments, and crowns and bridges. [(22)]

Following the review of the literature, it was determined that nearly all in-vitro work found that coating of orthodontic archwires with various materials improved the frictional resistance.[(23)]All research, however, suggested the use of coated orthodontic wires in the standard clinical orthodontic procedures after in-vivo human clinical trials. Accordingly, this study was conducted.

Friction is the force resisting the relative lateral motion of solid surfaces, fluid layers, or material elements in contact. Friction is derived from interaction of the electromagnetic force between the microstructure of the material such as electrons, protons, atoms and molecules. [(24)]

Orthodontic friction falls under the category of dry friction and is caused by the contact of the wire, ligature, and bracket slot. The relative lateral motion of two solid surfaces in contact is resisted by dry friction. Only the microscopic peaks on the surfaces make contact when two materials slide over one another. It is referred to these peaks as asperities. There are two types of dry friction: kinetic and static. [(25)]

Friction between two solid objects that are not moving in relation to one another is known as static friction. Its magnitude is necessary to start motion before it moves. When two things are moving in relation to one another is known as kinetic friction. Because there is no continuous motion of the teeth along an archwire, kinetic friction is less significant in the field of orthodontics. Tooth movement happens at a rate of less than 1 mm per month, which brings the process closer to a situation where static friction is more representative.(25)

There is more involved in the resistance of tooth movement than just friction. Resistance of tooth movement can be divided into three distinct elements:The first element is the "classical friction," which is further separated into kinetic and static friction, and it happens between the wire and bracket surfaces.The next part is the "binding" that takes place when a wire is bent, or a tooth is tipped to contact the bracket's edge.The third element is "notching," which is a permanent deformation of the wire at the interface between the wire and the bracket that prevents the teeth from moving until the notch is released.Consequently, the combined effects of binding, notching, and friction equal the resistance to tooth movement.(26)

During designing research module to study friction in vitro, friction can be studied inpassive or active configurations. Passive configurations are when the contact angle between the archwire and bracket slot is less than the critical contact angle. When passive configuration is applied, only classical friction controls sliding mechanics because binding and notching are not occurring. As the contact angle between the wire and bracket increases, friction becomes less relevant and binding and notching become greater forces resisting movement.Classical friction controls sliding mechanics only when the contact angle between the bracket and wire is less than 3.7 degrees. (26)

Although friction is a straightforward orthodontic component to research, it can be challenging to do so in a way that accurately simulates the intraoral experience.Although techniques for investigating friction in vivo have been established, most of the research is based on in vitro investigations because of their more straightforward nature.

<u>Limitations of invitro studies:</u>Studies conducted in vitro are subject to several restrictions. Firstly, most studies are passive systems that only measure friction after the binding and notching components have been eliminated. In these experiments, a bracket is mounted in such a way that the wire is dragged through it exactly parallel to the slot, creating no angle between the wire and the bracket. All they measure is the friction that exists between the ligature, bracket, and wire.

<u>Advantages of in vitro studies:</u>These investigations have the benefit of determining the precise amount of friction caused by the wire, bracket, and ligature type without the need for additional variables. The drawback is that the brackets are frequently positioned in ways that are anything but passive toward one another in clinical settings.

Some authors reported that resistance to sliding increases as the contact angle between the bracket and the archwire increasesand this finding was confirmed in multiple studies.(27) as in a study comparing between resistance to sliding in passiveversus active configurations were performed with varying bracket and archwire materials.(28)When the angulation between the bracket and the archwire exceeded just 3°, binding equaled or exceeded friction. Binding made up at least 80% of the resistance to sliding at $\theta=7°$ and as much as 99% at $\theta=13°$ for a stainless-steel wire in a ceramic bracket. Due to the importance of binding in the study of resistance to sliding, many friction studies have attempted to add the component of varying angulations between the wire and bracket slot. (29)

A secondary constraint on the passive in vitro friction research is the lack of slight alterations or disruptions that are typically caused by different oral functions. Random, small movements occur within the orthodontic appliance during speech, chewing, swallowing, or contact with food or tissues. These motions cause the archwire to shift in the bracket slot. It has been demonstrated that this movement modifies the appliance's friction.In a study attempting to measure this aspect. They mounted brackets at different angulations and pulled different sizesof orthodontic arch wires through them with an Instron while applying simulated oral perturbations. They found that perturbations caused the frictional resistance to momentarily become zero. [30]

When in vitro studies stimulated with these perturbations, variables such the bracket angulation, archwire/slot clearances, and ligature did not have a detectable impact on friction. These friction reductions could play a major role in the equation if the average frequency of masticatory interactions is between 32 and 80 cycles per minute. It was observed that the binding and notching at the bracket/archwire interface were momentarily removed, which resulted in the resistance being lowered to zero. These studies showed that random, intermittent, repeated, minute relative motions at the bracket/arch wire interface significantly reduced, if not completely eliminated, frictional resistance, and that the majority of previous in vitro frictional resistance experiments do not reflect the mode of frictional resistance that may actually occur in the oral cavity. This happens periodically when a person chews, speaks, swallows, and when their tissues and food come into touch with the orthodontic appliance.

As with most research, the wide heterogenicity in methodologies makes direct comparison amongst these studies difficult. There are many different types of brackets, numbers of brackets, wire sizes, different coating materials, types and timing of lubrication, and machine sizes and settings used throughout the literature. Also, there are no systematic reviews pertaining directly to the different type of ceramics nanoparticles coated wires and its effect on friction. Due to these discrepancies in methodology and the lack of high levels of evidence, no definite conclusions can be made on which coating materials has the lowest level of friction and if it has clinical significance. So, it is almost in all studies it was recommended to conduct a control clinical trials to measure the significance of wire coating regarding the rate of tooth movements.

In this clinical trial, patients were divided into 3 cohorts. Each patient had a control side with a conventional bracket (not coated) and a conventional archwire (not coated) this side was used as a control for the study side. According to different cohort’s study side are divided into; side (coated wire and coated bracket), (coated wire and uncoated bracket) and (uncoated wire and coated bracket). It was coded as mentioned before: OO (uncoated wire and uncoated bracket), ZZ (coated wire and coated bracket), ZO (coated wire and uncoated bracket) and OZ (uncoated wire and coated bracket).

Unexpectedly the results were:All Cohorts showed statistically significant different between the control side and the study side.The very un-expected results were; in the study side of (Cohort A) in which both wires and brackets were coated with Zno2, the rate of canine retraction was the slowest of all groups. Also, in the study side of (Cohort C) in which the wires were uncoated, and brackets were coated with Zno2, the rate of canine retraction was slower than the control side. The highest rate of canine retraction was the fastest at (Cohort B) at the study side in which only coating of the wires were used with uncoated brackets.Regarding to the unexpected finding, there are some interpretation of the results: In the in-vitro study we used a zero tip zero torque brackets which, as discussed before, eliminate almost the binding effect thus reduce frictional resistance. Even in our in-vivo study we used a round (0.020-inch) wire to reduce the binding effect, canine tilting and up-righting occurred thus binding to a degree is inevitable. The unexpected part was that in cases in which both the wires and the brackets were coated, the rate of canine movement was reduced. Our interpretation was that even with the thickness of the coated layers was as thin as almost (1.8 µm) at wires surface when engagement with bracket coating friction resistance increased. One interpretation was due to the microns decrease in slot size. Other interpretation was that due to bracket interface heterogenicity and mutable surface and slot morphology was interfered by NP coating lead to different micro deposition inside brackets slot that lead to be more resistance for archwires to slide. That also explains when only brackets coating also slowed the sliding in the cohort in which coated brackets only used with a conventional uncoated wire. Also, another explanation was that delamination occurs at bracket wire interface in the oral cavity that obstruct the sliding. As it is consented among all literatures that studied tooth movement, the rate of tooth movement is a multifactorial process. As during the navigation in our in-vitro study and the process of review of the literature, there was a lack of any in-vivo investigation regarding any controlled clinical trials study ceramics coated orthodontic appliance. Even with a known heterogenicity of the available data a randomized control clinical trial had to be done with as much as possible controlling the variables that might give us an insight of the efficacy of NP coated appliances. As mentioned in the discussion of the methodology most trials investigating canine retraction use a split-mouth design as their preferred experimental model. This assumes baseline equivalence between opposite sides of the dental arch and independence to different bilateral interventions, which reduces sample size requirements. Although experimentally convenient, split-mouth designs should be avoided and randomization be carried out at the level of the individual, not the dental arch but in that design another variable arise which is the biological factors and occlusal interferences thus occlusal load differences and a lot of other variables which are undoubtedly will significantly affects the target objective of study.

Conclusion

This study suggests that the zirconia coated nickel titanium orthodontic archwires create less friction compared with non-coated appliance. Even with our conclusion regarding the clinical performance of the coated archwire, it was concluded tooth movement is a multifactorial process and a minor part is the friction between brackets and wire. So, variables are not limited to brackets wire interface and that was revealed as the unexpectedly coating both archwire and brackets in the clinical practice acted negatively by reducing the rate of canine retraction. So, it is recommended for more clinical trials to study the behavior of coated wires under different conditions and it is important to navigate the clinical behavior with different research modules.

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