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Original Research Article

Characterisation, comparison of surface topography and frictional resistance of zinc oxide- tin oxide nanocoated ceramic orthodontic brackets by radio frequency magnetron sputter coating method: An in vitro study

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A B S T R A C T

Introduction: In recent years, orthodontic research has witnessed significant progress as it ventures into the exploration of nanoparticle coating to augment the surface properties of orthodontic appliances.
The present study aimed to evaluate the surface characteristics, surface topography and frictional resistance (FR) of ceramic brackets (CB) nanocoated with zinc oxide- tin oxide (ZnO-SnO_2) by radio frequency magnetron sputter coating method.
Materials and Methods: 26 polycrystalline maxillary canine CB, split into two groups, were used in the current in vitro investigation. Group A of the RF magnetron sputter coating method was used to coat ZnO-SnO_2 nanoparticles (Nps) on brackets, while group B of the process used uncoated brackets. Following coating, brackets underwent EDAX and SEM imaging. Atomic force microscopy (AFM) was used to assess the surface topography, and frictional resistance (FR) was also examined. An analysis of the data was conducted using SPSS (Version 23.0). An independent parametric t-test was used to compare the results between the groups.
Results: Brackets coated by RF sputter coating method had a porous and aggregated morphology when viewed under SEM. EDAX spectroscopy images showed uncoated brackets presented aluminium, oxygen, silica and calcium signal peaks at 60.83 wt %, 13.43 wt %, 24.57 wt % and 1.17 wt % respectively while the coated brackets showed signal peaks of zinc, oxygen, silica and tin at signal peaks of 20.98 wt %, 54.85 wt %, 10.52 wt % and 13.65 wt %. Groups A and B showed a surface roughness (SR) of 180.62 ± 9.49 nm and 316.77 ± 14.10. A statistically significant difference was observed in the SR between the 2 groups (p=0.00). The mean FR were higher for uncoated brackets (8.18 ± 0.76) p=0.00.
Conclusion: Zn-SnO2 Nps were effectively coated onto ceramic brackets through the RF magnetron sputter coating technique. In comparison to uncoated brackets, the coated brackets exhibited a lower FR and SR.

1. Introduction

Fixed orthodontic treatment involves the use of orthodontic brackets to align teeth and correct malocclusions. Orthodontic brackets are bonded to the teeth and connected to an arch wire to apply force and move the teeth into the desired position. The success of orthodontic treatment depends on several factors, including the design and material properties of the brackets.[1,2] Factors that affect the performance of orthodontic brackets are their surface properties, such as SR and FR.[3,4] The SR of orthodontic brackets can cause adhesion of bacteria and plaque, which

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can lead to dental caries and periodontal disease that can affect the efficiency of tooth movement during orthodontic treatment.[5–7]

Over the past few decades, nanotechnology has become a major technological breakthrough. This has broad applications in many fields, including health care, and is arguably one of the most quickly developing fronts in recent years.[8] Research in the rapidly developing subject of nano dentistry has been exponential, with different Nps being added to various dental materials to improve their qualities.[9] Nanocoatings are thin films of materials that are deposited on the bracket surface to alter their surface characteristics. It has shown to enhance the surface properties of brackets, such as SR and FR.[10] The RF magnetron sputter coating method is a widely used technique for depositing thin films of materials.[11–13] This method involves the use of a magnetron to generate a plasma of the coating material, which is then deposited on the surface of the orthodontic bracket. This method offers several advantages over other coating methods, such as high deposition rates, good adhesion, and uniform coating thickness.[14,15]

Despite being favoured for their aesthetic qualities, CB have drawbacks when it comes to orthodontic treatment. One notable disadvantage is increased friction and wear against the orthodontic archwire, which may impact the efficiency of tooth movement.[6,16] The ceramic material, though durable, is more brittle compared to traditional metal brackets, making them susceptible to breakage, especially during the early stages of treatment.[17] Park et al in 2010 evaluated the SR of monocrystalline and polycrystalline ceramic bracket slots and stainless steel brackets using an atomic force microscope. It was concluded that the SR of stainless steel brackets was the least followed by monocrystalline ceramic brackets and the highest in polycrystalline ceramic brackets.[18]

Due to its anti-inflammatory, antifungal and antibacterial qualities, the white odourless, ZnO Nps are used extensively. It reduces SR when coated on orthodontic brackets and wires, which reduces friction and treatment time overall.[19] Tin oxide (SnO_2) Nps have photocatalytic, antioxidant, and antibacterial activities that are useful in biomedicine.[20] The present study aimed to coat ceramic orthodontic brackets using a combination of ZnO-SnO_2 Nps by RF magnetron sputter coating method to evaluate the surface characterization, surface topography and frictional resistance (FR).

2. Materials and Methods

In this in vitro study, 26 polycrystalline ceramic brackets with a 0.022 slot MBT prescription maxillary canine brackets were utilized (Ormco Symetri, California, USA). The brackets were coated with a combination of ZnO-SnO_2 Nps. The technique of RF magnetron sputter coating was used to coat the Nps. 13 ceramic brackets coated with ZnO-SnO2 Nps made up one group, while uncoated brackets were included in another. The coated brackets were then assessed for characterisation, chemical analysis, surface topography, and FR.

2.1. *Method of coating the brackets*

Sputter deposition is a method of physical vapor deposition used to deposit thin films. In this process, Nps are emitted from a target and then deposited onto the substrate (bracket surface). The brackets are positioned within a vacuum chamber and reduced to a predetermined process pressure. Sputtering commences with the application of a negative charge to the target material (Nps), inducing a plasma or glow discharge. Positively charged gas ions produced in the plasma area are rapidly drawn toward the negatively biased target plate. The resulting collisions lead to a momentum transfer, expelling atomic-sized particles from the target. The bracket surface is then coated with a thin layer of these particles. The coating was applied to one side of the substrate, resulting in a uniform thickness of 300 nm. Prior to the coating process, the substrates underwent a 30-minute ultra-sonication clean in a mixture of acetone and isopropyl alcohol to remove any grease, gunk, or finger contamination. The uniformity of the coating was measured with a standard deviation of 15 to 25%. The radio frequency magnetron sputtering tool used in this study was an HHV Pumps model 200KTH, which featured a base pressure of 5 e-6 Torr, and a RF gun frequency of 14.56 MHz, and a deposition rate of 25 Å/s. The deposition process took place at room temperature and a pressure of 5 e-6 Torr, with sputter power levels ranging from 50 to 80 watts. SEM was used to evaluate the morphology of the coating, and its chemical composition was analyzed using EDAX. AFM was utilized to assess the surface topography of the treated brackets, while the universal testing machine measured FR.

2.2. *SEM*

High-resolution SEM was used in the morphological analysis to analyse the surface properties of the coated brackets. The samples were sputter-coated in gold, mounted on aluminium stubs using carbon tape, and viewed under a scanning electron microscope.

2.3. *EDAX*

Using EDAX, the Nps on the brackets were identified for the constituent elements, and the chemical composition of the coated brackets was examined in the chemical investigations.

2.4. *AFM*

The coated bracket surface was imaged and measured at the nanoscale using AFM to evaluate surface topography. This gave information on the SR in the 500–1000 nm range. Both the groups of brackets were subjected to no contact mode AFM examination using the Anton Parr-Step 700 Surface testing instrument.

2.5. FR

A model 4468 of the Instron Universal Testing Machine (UTM) from the Instron Corporation in Canton, Massachusetts was used to evaluate FR. An aluminium plate was attached to the brackets using cyanoacrylate adhesive. The plate was fastened to the UTM's lower part. The bracket and wire could be moved linearly as the 0.019 × 0.025 inch SS wires were ligated to the brackets in the bottom component and the top end of the wire was fastened in the tension load cell, which moved at a cross-head speed of 0.5 mm/s.

3. Results

3.1. SEM

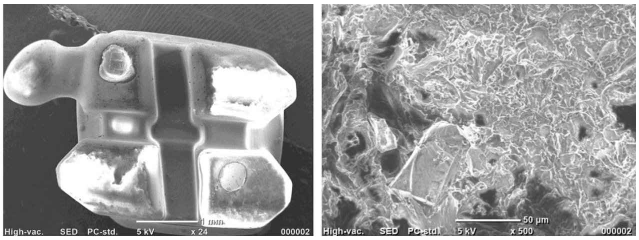
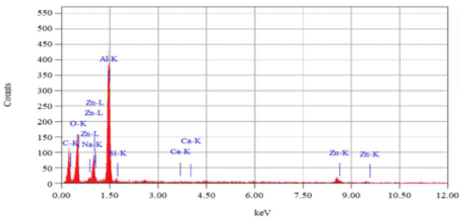


Figure 1: ZnO- SnO_2 Coated brackets

Figure 1 shows that the ZnO- SnO2 nanocoated brackets by RF sputter coating method had a porous and aggregated morphology when viewed under SEM at a resolution of 50 micrometres.

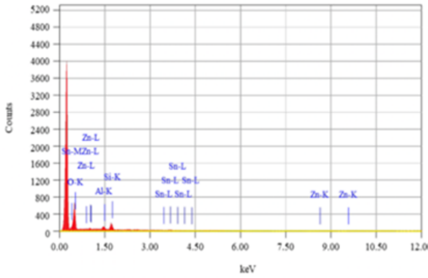
3.2. EDAX



Element	Weight %
Al	60.83
O	13.43
Si	24.57
Ca	1.17

Figure 2: Graph showing the EDAX spectroscopy of uncoated brackets

Figures 2 and 3 illustrate the EDAX spectroscopy images showing the chemical composition of the uncoated and coated brackets. Uncoated brackets showed aluminium, oxygen, silica and calcium signal peaks at 60.83wt %, 13.43



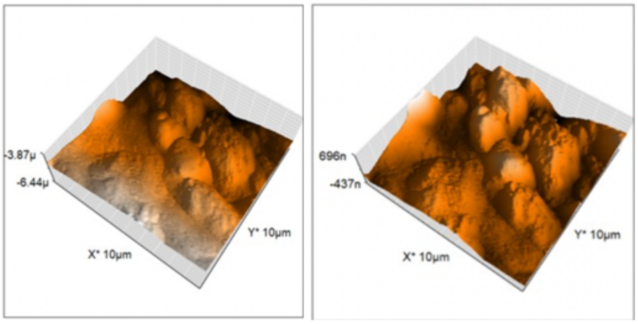
Element	Weight %
Zn	20.98
O	54.85
Si	10.52
Sn	13.65

Figure 3:

wt %, 24.57 wt % and 1.17 wt % respectively. ZnO-SnO2 Nps coated brackets showed signal peaks of zinc, oxygen, silica and tin at signal peaks of 20.98 wt %, 54.85 wt %, 10.52 wt % and 13.65 wt % hence confirming the chemical composition of the coated brackets.

3.3. AFM

Figure 4 illustrates the surface topography of the brackets coated by RF magnetron sputter coating method, which exhibits small nodular pattern with an average SR value of 180.62 ± 9.49 nm. Group B exhibits a rough surface with bigger nodules and an average surface roughness value of 316.77 ± 14.10. A statistically significant difference was observed in the SR between the 2 groups (p=0.00) as shown in Table 1.



Group A Group B

3.4. Frictional resistance

A significant mean difference in FR between groups A and B (p=0.00) was noted. The mean FR were higher for uncoated brackets (8.18 ± 0.76).

4. Discussion

The present study evaluated the morphological and chemical characteristics, SR, and FR of ceramic orthodontic brackets coated with ZnO-SnO2 Nps using an RF

Table 1: Mean comparison of surface roughness, frictional resistance among coated and uncoated brackets

Properties	**Mean ± SD**		**Mean difference**	**p value**
	Group A	Group B		
Surface roughness	180.62 ± 9.49	316.77 ± 14.10	-136.15	0.00
Frictional resistance	2.08 ± 0.85	8.185± 0.76	-6.00	0.00

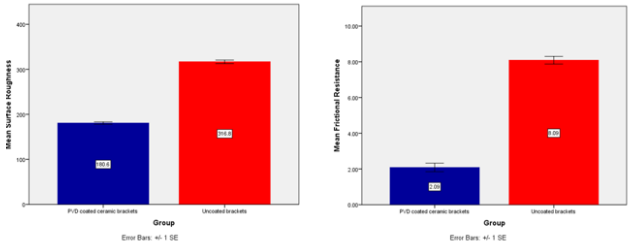


Figure 4: Graph depicting the mean surface roughness and frictional resistance between groups A and B

magnetron sputter coating method. The morphology of the coated brackets was porous and aggregated. EDAX spectroscopy was used to validate the composition of the Nps coated onto the brackets. The results showed that O, Zn, and Sn signal peaks were present, indicating the presence of ZnO-SnO_2 Nps. On comparing the SR by AFM, of both the groups, the coated brackets showed a lower SR when compared to the uncoated brackets. RF magnetron sputter-coated brackets had a lower FR than non-coated brackets.

Ceramic brackets have rougher surfaces when compared to metal brackets, which affects the sliding of archwires and, consequently, affects the teeth movement.[21] In order to evaluate the SR of CB and SS brackets, Lee et al. performed an AFM study in 2010 and the results of the investigation showed that SS brackets had a lower SR in the range of 36.53 to 58.94 nm, whereas CB showed a SR in the range of 303.75 to 394.21 nm.[22] An in vitro investigation was conducted by Thomas et al. in 2021 to assess the FR between SS, CB, and metal insert ceramic brackets. It was observed that FR on using 0.019 x 0.025" SS wire was highest for CB, while FR was similar in SS brackets and metal insert CB.[23] An in-vitro study by AlSubaie et al. compared the FR and surface topography of SS brackets, monocrystalline ceramic brackets (MCA), and polycrystalline ceramic brackets (PCA).[24] The FR of the PCA and SS brackets was found to be considerably lower than the FR of the MCA bracket.

To lower the FR, ceramic brackets were coated by Nps in the previous research. Arici et al evaluated the FR of brackets and archwires coated with aluminium oxide (Al2O3), titanium nitride (TiN) and chromium nitride (CrN) by RF magnetron sputter coating method. The study found that the TiN and Al2O3 coatings were successful in decreasing the FR between the brackets and archwires, while the CrN coating showed the poorest results.[25] Zhang et al. in 2023 found that coating TiN on metal brackets with RF magnetron sputtering can lower the FR by 50%.[26]. These coatings are effective in reducing friction and improving the performance of orthodontic appliances. Hence RF magnetron sputter coating method was used in the present study to coat the brackets to assess the SR and FR.

In an in vitro investigation, Tawakal et al. assessed the FR and SR of MCA, PCA, and SS brackets coated with silver and silver chitosan Nps as well as uncoated brackets. It was discovered that there was no discernible effect of nanocoating on the FR and SR of ceramic brackets.[27] Therefore silver Nps were not used for coating the brackets. In a clinical investigation, Shaik and Guram used CB, metal insert ceramic brackets and SS brackets to assess the rate of canine retraction. The FRs produced by ceramic brackets with metal slots were lower than those of ceramic brackets but greater than those of SS brackets.[28] An in-vitro study by Behroozian et al. (2016) evaluated the impact of ZnO Np coating on the FR between orthodontic wires and ceramic brackets. It was observed that FR was lowest for coated brackets and uncoated wires (2.18±0.5 N) and highest for coated brackets and wires (3.07±0.4 N).[29] Hence the present study used ZnO-SnO_2 Nps to coat the ceramic brackets inorder to alter the mechanical properties.

The study's constraints lie in its in vitro nature, necessitating an in vivo evaluation for result confirmation. Further investigations could focus on assessing the antimicrobial effectiveness of the coated brackets, aiming to diminish the occurrence of caries and periodontal conditions during orthodontic treatment.

5. Conclusion

Zn-SnO2 Nps were effectively coated onto ceramic brackets through the RF magnetron sputter coating technique. The presence of the Nps was confirmed by characterization. In comparison to uncoated brackets, the coated brackets exhibited a lower FR and SR.

6. Source of Funding

None.

7. Conflict of Interest

None.

References

1. Jian F, Lai W, Furness S, Mcintyre GT, Millett DT, Hickman J. Initial arch wires for tooth alignment during orthodontic treatment with fixed appliances. . *Cochrane Database Syst Rev*. 2013;4:7859.
2. Mavreas D, Athanasiou AE. Factors affecting the duration of orthodontic treatment: a systematic review. *Eur J Orthod*. 2008;30(4):386–95.

3. Sarul M, Mikulewicz M, Kozakiewicz M, Jurczyszyn K. Surface Evaluation of Orthodontic Brackets Using Texture and Fractal Dimension Analysis. *Materials*. 2022;15(6):2071.
4. Pacheco MR, Jansen WC, Oliveira DD. The role of friction in orthodontics. *Dental Press J Orthod*. 2012;17(2):170–7.
5. Doshi UH, Bhad-Patil WA. Static frictional force and surface roughness of various bracket and wire combinations. *Am J Orthod Dentofac Orthop*. 2011;139(1):74–83.
6. Pillai AR, Gangadharan A, Kumar S, Shah A. Comparison of the frictional resistance between archwire and different bracket system: An in vitro study. *J Pharm Bioallied Sci*. 2014;6(1):150–5.
7. Frank CA, Nikolai RJ. A comparative study of frictional resistances between orthodontic bracket and arch wire. *Am J Orthod*. 1980;78(6):593–609.
8. Zakrzewski W, Dobrzynski M, Dobrzynski W, Zawadzka-Knefel A, Janecki M, Kurek K. Nanomaterials Application in Orthodontics. . *Nanomaterials*. 2021;11(2):337.
9. Padmanabhan S. *Nanotechnology in Orthodontics Semin Orthod*. 2023;29(1):79–84.
10. Bącela J, Łabowska MB, Detyna J, Zięty A, Michalak I. Functional Coatings for Orthodontic Archwires-A Review. *Materials*. 2020;13(15):3257.
11. Harish V, Ansari MM, Tewari D, Gaur M, Yadav AB, García-Betancourt ML, et al. Nanoparticle and Nanostructure Synthesis and Controlled Growth Methods. . *Nanomaterials (Basel)*. 2022;12(18):3226.
12. Kumar AA, Jain RK. Synthesis and characterization of the zinc-oxide: Tin-oxide nanoparticle composite and assessment of its antibacterial activity: An in vitro study. *Cureus*. 2024;16(1):e53016.
13. Patil N, Bhaskar R, Vyavhare V, Dhadge R, Khaire V, Patil Y. Overview on methods of synthesis of nanoparticles. *Int J Curr Pharm Res*. 2021;13:11–7.
14. Lee SJ, Hwang CS, Pi JE, Ryu MK, Oh H, Cho SH, et al. Characterization of ZnO-SnO2 nanocomposite thin films deposited by pulsed laser ablation and their field effect electronic properties. *Mater Lett*. 2014;122:94–101.
15. Satheesh R, Sankar S, Gopchandran KG. Effect of radio frequency power on magnetron sputtered TiO2 thin films. Apple Academic Press; 2017. p. 185–201.
16. Gkantidis N, Zinelis S, Karamolegkou M, Eliades T, Topouzelis N. Comparative assessment of clinical performance of esthetic bracket materials. *Angle Orthod*. 2012;82(4):691–8.
17. Forsberg CM, Hagberg C. Shear bond strength of ceramic brackets with chemical or mechanical retention. *Br J Orthod*. 1992;19(3):183–92.
18. Park KH, Yoon HJ, Kim SJ, Lee GJ, Park HK, Park YG. Surface roughness analysis of ceramic bracket slots using atomic force microscope. *Korean J Orthod*. 2010;40(5):294–294.
19. Kachoei M, Eskandarinejad F, Divband B, Khatamian M. The effect of zinc oxide nanoparticles deposition for friction reduction on orthodontic wires. *Dent Res J*. 2013;10(4):499–505.
20. Haq S, Ahmad P, Khandaker MU, Faruque M, Rehman W, Waseem M, et al. Antibacterial, antioxidant and physicochemical investigations of tin dioxide nanoparticles synthesized via microemulsion method. . *Mater Res Express*. 2021;8(3):35013.
21. Williams CL, Khalaf K. Frictional resistance of three types of ceramic brackets. *J Oral Maxillofac Res*. 2013;4(4):3–3.
22. Lee GJ, Park KH, Park YG, Park HK. A quantitative AFM analysis of nano-scale surface roughness in various orthodontic brackets. *Micron*. 2010;41(7):775–82.
23. Jnaneshwar P, Thomas P, Rajaram K, Kishore S, Venkatesan K. Comparative evaluation of frictional forces between ceramic brackets, metal insert ceramic brackets, and conventional metal brackets with three different arch wires: An in vitro study. *Int J Orthod Rehabil*. 2021;12(1):1.
24. Alsubaie M, Talic N. Comparison of the static frictional resistance and surface topography of ceramic orthodontic brackets: an in vitro study. *Aust Orthod J*. 2017;33(1):24–34.
25. Arici N, Akdeniz BS, Oz AA, Gencer Y, Tarakci M, Arici S, et al. Effectiveness of medical coating materials in decreasing friction between orthodontic brackets and archwires. *Korean J Orthod*. 2021;51(4):270–81.
26. Zhang R, Han B, Liu X. Functional Surface Coatings on Orthodontic Appliances: Reviews of Friction Reduction, Antibacterial Properties, and Corrosion Resistance. *Int J Mol Sci*. 2023;24(8):6919.
27. Tawakal MS, Metwally A, El-Wassefy AM, Tawfik NA, Shamaa MA. Static friction, surface roughness, and antibacterial activity of orthodontic brackets coated with silver and silver chitosan nanoparticles. *J World Fed Orthod*. 2023;12(6):260–8.
28. Shaik JA, Guram G. A Comparative Evaluation of Canine Retraction Using Ceramic Bracket and Ceramic Bracket with Metal Slot with Conventional Preadjusted Edgewise Appliance Bracket Systems: A Clinical Study. *J Int Soc Prev Commun Dent*. 2018;8(4):296–303.
29. Behroozian A, Kachoei M, Khatamian M, Divband B. The effect of ZnO nanoparticle coating on the frictional resistance between orthodontic wires and ceramic brackets. *J Dent Res Dent Clin Dent Prospects*. 2016;10(2):106–17.

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