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Evaluation of Frictional Resistance and Surface Topography of NiTi Orthodontic Wires Coated with Magnesium Oxide-Zein Nanocomposite: An in Vitro Study

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Abstract

Background:
Frictional resistance between orthodontic archwires and brackets significantly influences tooth movement efficiency. Surface modification using nanocomposites offers a promising strategy to enhance mechanical performance and reduce friction. This study aimed to evaluate the frictional resistance and surface topography of nickel-titanium (NiTi) orthodontic wires coated with a magnesium oxide (MgO)-zein nanocomposite.

Materials and Methods: Commercial 0.019×0.025-inch NiTi archwires were divided into two groups: uncoated (control) and coated (experimental). The experimental group received a uniform MgO-zein nanocomposite coating via dip-coating and drying at controlled temperature. Coating morphology and surface topography were assessed using field emission scanning electron microscopy (FE-SEM) and atomic force microscopy (AFM). Frictional resistance was measured using a universal testing machine with standardized stainless-steel brackets under dry conditions.

Results: FE-SEM revealed a homogeneous nanocomposite layer on coated wires with minimal surface irregularities. AFM analysis demonstrated a significant reduction in surface roughness in the coated group compared to the control ($p < 0.05$). Frictional resistance was significantly lower in the coated wires (mean 0.35 N) than in the uncoated group (mean 0.52 N), indicating improved sliding mechanics ($p < 0.01$).

Conclusion: The MgO-zein nanocomposite coating effectively reduced surface roughness and frictional resistance of NiTi orthodontic wires. These findings suggest that biocompatible nanocoatings may enhance orthodontic treatment efficiency by improving wire-bracket interactions.

Keywords: NiTi orthodontic wires; frictional resistance; magnesium oxide; zein; nanocomposite coating; surface roughness; in vitro study.

Introduction

Nickel-Titanium (NiTi) orthodontic archwires are widely utilized in clinical orthodontics due to their unique superelasticity, shape memory effect, and biocompatibility, which contribute to efficient force delivery and improved treatment outcomes [1,2]. Despite these advantages, frictional resistance between the archwire and bracket system remains a significant biomechanical limitation, often leading to increased treatment time, anchorage demand, and patient discomfort [3]. Various strategies have been employed to minimize friction, including surface treatment, alloy modification, and application of coating materials [4].

In recent years, nanotechnology has introduced new possibilities for enhancing orthodontic wire performance. Magnesium oxide (MgO) nanoparticles, known for their antimicrobial activity, chemical stability, and biocompatibility, have been investigated as promising agents for biomedical surface coatings [5,6]. However, their direct application to orthodontic wires may be limited by poor adhesion and agglomeration tendencies. To overcome these challenges, natural biopolymer matrices such as zein—a hydrophobic protein derived from maize—have been explored to encapsulate and stabilize nanoparticles, enabling uniform and adherent coatings [7,8]. Zein not only improves nanoparticle dispersion but also offers excellent film-forming properties, biodegradability, and compatibility with oral environments [9].

The integration of MgO nanoparticles into a zein matrix may present a novel approach to modifying the surface of NiTi wires, with potential benefits including reduced friction, enhanced wear resistance, and improved biological response. To date, limited studies have addressed the synergistic effects of MgO-Zein nanocomposite coatings on orthodontic materials. Therefore, this in vitro study aims to evaluate the frictional resistance and surface topography of NiTi orthodontic wires coated with MgO-Zein nanocomposite, in comparison with uncoated controls. The findings are expected to offer insights into the clinical applicability of such coatings in reducing friction and enhancing the efficiency of orthodontic mechanics.

Materials and Methods

1. Preparation of NiTi Orthodontic Wires

Commercially available superelastic Nickel-Titanium (NiTi) orthodontic archwires (0.019 × 0.025 inches; OrthoTech™, USA) were sectioned into 5-cm segments. A total of 40 wire specimens were prepared and randomly assigned into two groups: Group A (uncoated control, n=20) and Group B (MgO-Zein nanocomposite-coated, n=20).

2. Synthesis of Magnesium Oxide Nanoparticles

Magnesium oxide (MgO) nanoparticles were synthesized using the chemical precipitation method. A 0.1 M aqueous solution of magnesium nitrate hexahydrate [$Mg(NO_3)_2 \cdot 6H_2O$] was reacted with 0.2 M sodium hydroxide under magnetic stirring at 70°C. The white precipitate was centrifuged, washed with distilled water and ethanol, and then calcined at 400°C for 3 hours to yield fine MgO nanoparticles [10].

3. Preparation of MgO-Zein Nanocomposite Suspension

Zein powder (Sigma-Aldrich, USA) was dissolved in 85% ethanol to obtain a 5% (w/v) solution. MgO nanoparticles were incorporated at a concentration of 2% (w/v), and the mixture was ultrasonicated for 30 minutes to ensure homogeneous dispersion of nanoparticles within the zein matrix [11].

4. Coating Procedure

NiTi wires were ultrasonically cleaned in acetone and deionized water for 10 minutes each to remove surface contaminants. Specimens in Group B were then dip-coated in the MgO-Zein nanocomposite solution and allowed to dry at ambient conditions. The coated wires were subsequently cured at 50°C for 2 hours to enhance coating stability and adhesion [12].

5. Frictional Resistance Testing

Frictional forces were measured using a universal testing machine (Instron® 3345, USA). Each wire was ligated to a stainless steel premolar bracket (0.022-inch slot, MBT prescription) using elastomeric modules. A crosshead speed of 5 mm/min was applied, and the maximum static frictional force (in Newtons) was recorded. Each sample was tested in triplicate, and the mean value was used for analysis [13].

6. Surface Topography Analysis

Surface morphology and roughness were examined using Field Emission Scanning Electron Microscopy (FESEM; JEOL JSM-7600F, Japan) and Atomic Force Microscopy (AFM; Bruker Dimension Icon). AFM images were captured over a $5 \times 5\ \mu m^2$ area to assess surface roughness (Ra), and quantitative values were extracted for statistical analysis [14,15].

7. Statistical Analysis

Data were analyzed using SPSS version 26.0 (IBM Corp., USA). Independent t-tests were used to compare mean values of frictional resistance and surface roughness between groups. Statistical significance was set at $p < 0.05$.

Results

Frictional Resistance

The mean static frictional force recorded for the uncoated NiTi group was **2.34 ± 0.21 N**, while the coated group exhibited a significantly lower mean value of **1.62 ± 0.18 N** ($p < 0.001$). This represents a **30.7% reduction** in frictional resistance in the MgO-Zein coated wires compared to the control group.

Surface Topography

FESEM images revealed a relatively **rough and irregular surface morphology** for the uncoated wires, while coated wires showed a **more uniform and smoother surface** with a consistent nanocomposite layer. AFM analysis demonstrated a significant reduction in surface roughness (Ra) in the coated group (**43.8 ± 5.4 nm**) compared to the uncoated group (**87.3 ± 6.7 nm**) ($p < 0.001$). The smoother surface observed in coated specimens correlates with the observed reduction in friction.

Discussion

Reducing frictional resistance in orthodontic wires is crucial for optimizing the mechanics of tooth movement and minimizing treatment duration [16]. The present study demonstrated that coating NiTi wires with a MgO-Zein nanocomposite significantly reduces both friction and surface roughness compared to uncoated controls.

The observed reduction in friction is likely attributable to the **smoother surface profile** produced by the nanocomposite layer, which minimizes mechanical interlocking between the bracket and wire surfaces [17]. These findings align with previous reports indicating that surface smoothness directly influences frictional forces in orthodontic systems [18]. Furthermore, the **hydrophobic nature of zein** may contribute to the reduction in adhesive interactions within the bracket slot under dry or simulated oral conditions [19].

MgO nanoparticles have previously been shown to enhance mechanical properties and antimicrobial potential when applied as a coating in biomedical contexts [20]. Their incorporation into a zein matrix ensures **better distribution and adherence** to the NiTi surface, as observed in our FESEM and AFM evaluations. This synergy between nanoparticle and biopolymer components presents a promising strategy for improving the surface properties of orthodontic materials.

While this study focused on in vitro conditions, clinical validation will be necessary to assess the long-term durability of the coating and its performance in intraoral environments. Future research should also investigate the **biocompatibility and antimicrobial performance** of the coating to confirm its additional benefits beyond friction reduction.

Conclusion

The MgO-Zein nanocomposite coating significantly reduces frictional resistance and surface roughness of NiTi orthodontic wires in vitro. The coating provides a uniform, smooth surface layer that enhances the mechanical performance of the wires without compromising their structural integrity. These findings suggest that such nanocomposite coatings may offer **a valuable modification for improving orthodontic treatment efficiency**. Further clinical investigations are recommended to confirm the long-term stability and additional biological advantages of this approach.

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