International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 15s,2025
https://theaspd.com/index.php

# Study On Surface-Modified Orthodontic Wires By Different Concentration Of Titanium Oxide Nanoparticles

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***Abstract***
***Background:****Surface modification of orthodontic wires has emerged as an innovative approach to enhance their mechanical and biological properties. Titanium oxide ($TiO_2$) nanoparticles are well-known for their antimicrobial, anti-frictional, and corrosion-resistant properties. This study investigates the effect of different concentrations of $TiO_2$ nanoparticles on the surface characteristics and performance of stainless steel orthodontic wires.*
***Materials and Methods:****Commercial stainless steel orthodontic wires (0.019" × 0.025") were surface-treated using $TiO_2$ nanoparticles at concentrations of 0.5%, 1.0%, and 1.5% (w/v) via the dip-coating method. The coated wires were subjected to surface characterization using scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and atomic force microscopy (AFM) to assess surface morphology and roughness. Frictional resistance was evaluated using a universal testing machine under wet conditions. Antimicrobial activity was assessed against Streptococcus mutans using the zone of inhibition method. Data were analyzed using ANOVA and Tukey's post hoc test.*
***Results:****SEM analysis revealed uniform nanoparticle deposition with increasing coverage at higher $TiO_2$ concentrations. AFM showed a reduction in surface roughness values from 110 nm (control) to 76 nm (1.5% $TiO_2$). The coefficient of friction decreased significantly in the 1.0% and 1.5% $TiO_2$ groups (0.21 and 0.19, respectively) compared to the control (0.31). Antibacterial testing showed maximum inhibition zone diameter in the 1.5% $TiO_2$ group (18.3 ± 1.2 mm), indicating enhanced antimicrobial efficacy ($p < 0.05$).*
***Conclusion:****Surface modification of orthodontic wires using titanium oxide nanoparticles significantly improved surface smoothness, reduced friction, and enhanced antimicrobial properties. The 1.5% $TiO_2$ concentration was found to be the most effective and may contribute to improved clinical outcomes in fixed orthodontic therapy.*
***Keywords:****Orthodontic wires, Titanium oxide nanoparticles, Surface modification, Friction reduction, Antimicrobial activity, Nanotechnology in orthodontics.*

## Introduction

Orthodontic treatment relies heavily on the mechanical performance and biocompatibility of archwires, which serve as the primary force-generating components for tooth movement. Stainless steel archwires are widely used due to their favorable properties such as high tensile strength, formability, and cost-effectiveness (1). However, friction at the bracket-wire interface, corrosion in the oral environment, and microbial colonization are significant limitations that can compromise treatment efficiency and patient comfort (2,3).To address these challenges, surface modification of orthodontic wires has gained attention as a method to enhance their performance without altering core mechanical properties. Among various surface treatment techniques, the use of nanomaterials—especially titanium oxide ($TiO_2$) nanoparticles—has shown promise due to their exceptional antibacterial activity, corrosion resistance, and ability to reduce friction (4,5). $TiO_2$ nanoparticles possess photocatalytic properties and have been effectively utilized in biomedical applications to inhibit bacterial adhesion and biofilm formation (6).

In the context of orthodontics, incorporating $TiO_2$ nanoparticles onto wire surfaces may not only improve antibacterial characteristics but also enhance surface smoothness, potentially lowering frictional resistance during sliding mechanics. Previous studies have indicated that $TiO_2$ coatings can significantly alter surface roughness and reduce friction at the bracket-wire interface (7,8). Despite these advancements, there remains limited data comparing the impact of varying concentrations of $TiO_2$ on the functional outcomes of orthodontic wires.Therefore, the present study aims to evaluate the effect of surface modification of stainless steel orthodontic wires with different concentrations of titanium oxide nanoparticles on surface characteristics, frictional resistance, and antibacterial efficacy.

## MATERIALS AND METHODS

**Study Design:**
This in-vitro experimental study was conducted to evaluate the effects of different concentrations of titanium oxide ($TiO_2$) nanoparticles on the surface characteristics and performance of stainless steel orthodontic wires.

**Sample Preparation:**
A total of 40 commercially available stainless steel rectangular orthodontic wires (0.019" × 0.025") were used and divided into four groups (n=10 each):

- Group I: Uncoated control wires
- Group II: Wires coated with 0.5% $TiO_2$ nanoparticles
- Group III: Wires coated with 1.0% $TiO_2$ nanoparticles
- Group IV: Wires coated with 1.5% $TiO_2$ nanoparticles

**Coating Procedure:**
$TiO_2$ nanoparticles (anatase phase, <100 nm) were dispersed in ethanol using a magnetic stirrer and ultrasonicator for 30 minutes to ensure uniform suspension. Wires were immersed in the respective nanoparticle solutions using the dip-coating technique and dried at room temperature. This process was repeated three times for even coating. After drying, wires were cured in a hot air oven at 60°C for 2 hours to ensure adherence of the nanoparticles.

**Surface Characterization:**
Surface morphology was examined using Scanning Electron Microscopy (SEM), while elemental analysis was conducted through Energy Dispersive X-ray Spectroscopy (EDS) to confirm nanoparticle presence. Surface roughness was assessed using Atomic Force Microscopy (AFM), and values were recorded in nanometers (nm).

**Frictional Resistance Test:**
Frictional resistance was measured using a universal testing machine. Each wire sample was tested against stainless steel brackets (0.022" slot) using a constant vertical load of 150 g and a crosshead speed of 5 mm/min under wet conditions (artificial saliva). The maximum static frictional force was recorded for each sample.

**Antimicrobial Testing:**
Antibacterial activity was evaluated using the agar well diffusion method against Streptococcus mutans. Sterile Muller-Hinton agar plates were inoculated with the bacterial suspension. Wire samples from each group were placed on the agar surface, and plates were incubated at 37°C for 24 hours. The zone of inhibition was measured in millimeters using a digital caliper.

**Statistical Analysis:**
Data were analyzed using SPSS software version 25.0. One-way ANOVA followed by Tukey's post hoc test was used to compare mean values among the groups. A p-value of <0.05 was considered statistically significant.

## RESULTS

The surface-treated wires with different concentrations of titanium oxide nanoparticles exhibited noticeable changes in surface morphology, roughness, frictional resistance, and antibacterial activity compared to the control group.

**Surface Morphology and Elemental Analysis:**
Scanning Electron Microscopy (SEM) revealed smooth and clean surfaces in the control group, while nanoparticle-treated groups showed increased surface coverage, especially in Group IV (1.5% $TiO_2$), which displayed dense and uniform distribution of nanoparticles. Energy Dispersive X-ray Spectroscopy (EDS) confirmed the presence of titanium in Groups II–IV, with increasing elemental peaks proportional to the nanoparticle concentration.

**Surface Roughness:**

Atomic Force Microscopy (AFM) demonstrated a significant reduction in surface roughness with increasing $TiO_2$ concentrations. Group IV exhibited the lowest surface roughness value.

**Table 1: Surface Roughness (Ra) of Orthodontic Wires (nm)**

| Group | $TiO_2$ Concentration | Mean Surface Roughness (Ra ± SD) |
|---|---|---|
| Group I | 0% (Control) | 110.4 ± 6.2 |
| Group II | 0.5% | 93.7 ± 5.4 |
| Group III | 1.0% | 82.1 ± 4.9 |
| Group IV | 1.5% | 76.3 ± 3.7 |

The reduction in roughness was statistically significant across all experimental groups compared to the control ($p < 0.05$).

**Frictional Resistance:**

A decreasing trend in static frictional forces was observed with higher concentrations of $TiO_2$. Group IV recorded the lowest friction value (Table 2).

**Table 2: Mean Frictional Resistance (N) of Wires**

| Group | $TiO_2$ Concentration | Mean Frictional Force (N ± SD) |
|---|---|---|
| Group I | 0% (Control) | 0.31 ± 0.04 |
| Group II | 0.5% | 0.26 ± 0.03 |
| Group III | 1.0% | 0.21 ± 0.02 |
| Group IV | 1.5% | 0.19 ± 0.02 |

Statistical analysis revealed significant differences between control and Groups III–IV ($p < 0.01$).

**Antibacterial Activity:**

All $TiO_2$-coated groups exhibited zones of inhibition against Streptococcus mutans, with Group IV demonstrating the highest antibacterial effect (Table 3).

**Table 3: Antibacterial Activity – Mean Zone of Inhibition (mm)**

| Group | $TiO_2$ Concentration | Inhibition Zone (mm ± SD) |
|---|---|---|
| Group I | 0% (Control) | 0.00 ± 0.00 |
| Group II | 0.5% | 10.2 ± 1.1 |
| Group III | 1.0% | 14.7 ± 1.5 |
| Group IV | 1.5% | 18.3 ± 1.2 |

Group IV showed a statistically significant increase in antibacterial efficacy compared to all other groups ($p < 0.001$) (Tables 1–3).

## DISCUSSION

The present study evaluated the effect of different concentrations of titanium oxide ($TiO_2$) nanoparticles on the surface properties, frictional resistance, and antimicrobial activity of stainless steel orthodontic wires. The findings demonstrate that $TiO_2$ nanoparticle coating significantly improved surface smoothness, reduced friction, and enhanced antibacterial activity, particularly at the 1.5% concentration.Surface modification plays a pivotal role in optimizing orthodontic materials to meet clinical demands. Stainless steel wires, although mechanically strong, are prone to increased surface roughness and plaque accumulation when exposed to the oral environment (1). In this study, SEM and AFM analyses confirmed that $TiO_2$ nanoparticle coatings improved surface uniformity and reduced roughness. Previous reports also support that nanoparticle coatings can fill surface micro-irregularities, leading to smoother topography and improved functional performance (2,3).Friction between the bracket and archwire is a critical factor in orthodontic tooth movement efficiency. Our results showed a progressive decrease in frictional forces with increasing $TiO_2$ concentration, with Group IV (1.5% $TiO_2$) exhibiting the lowest mean frictional value. This is consistent with earlier studies that demonstrated reduced friction with $TiO_2$-coated or surface-modified orthodontic wires due to lower surface energy and enhanced lubricity (4,5). Reduced friction is clinically advantageous, as it may shorten treatment time and decrease the required force levels, thereby minimizing root resorption and patient discomfort (6,7).The antibacterial assessment revealed a significant increase in the zone of inhibition with higher concentrations of $TiO_2$ nanoparticles. This is in line with studies highlighting the broad-spectrum antibacterial activity of $TiO_2$, especially against oral pathogens like Streptococcus mutans and Lactobacillus acidophilus (8,9). The photocatalytic property of $TiO_2$, which generates reactive oxygen species (ROS), disrupts bacterial cell membranes and inhibits biofilm formation (10,11). Such antibacterial coatings are crucial in preventing white spot lesions and periodontal inflammation during fixed orthodontic treatment (12).The elemental analysis via EDS confirmed the successful incorporation of titanium on wire surfaces, indicating the stability of the coating process. Moreover, the use of dip-coating, being a cost-effective and reproducible technique, has previously been validated for biomedical coatings (13). Our results support its applicability in orthodontic wire enhancement.

Despite promising findings, this study has limitations. Being in-vitro, it does not fully simulate the dynamic oral environment, including salivary enzymes, masticatory forces, and dietary factors, which may influence coating durability and clinical efficacy. Additionally, long-term cytotoxicity and tissue compatibility of such surface modifications should be evaluated before clinical translation (14,15).

## CONCLUSION

In conclusion, surface treatment of orthodontic stainless steel wires with $TiO_2$ nanoparticles at increasing concentrations demonstrated favorable modifications, including smoother surface, reduced friction, and enhanced antimicrobial properties. These findings suggest potential clinical benefits in reducing treatment time and minimizing microbial complications during orthodontic therapy.

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