

In Vitro Assessment of Titanium Particle Release During Simulated Surgical Insertion of Dental Implants

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ABSTRACT

Background: Titanium dental implants are widely used due to their excellent biocompatibility, mechanical strength, and corrosion resistance. However, the process of insertion can lead to the exfoliation of titanium particles, which may influence osseointegration and contribute to peri-implantitis. This study aims to evaluate the extent of titanium exfoliation during simulated surgical insertion of dental implants in an artificial bone model.

Materials and Methods: In this in vitro study, a total of 30 titanium dental implants (n = 10 per group) were inserted into standardized artificial bone blocks using a simulated surgical insertion protocol. Three different insertion torques were applied: Low Torque (25 Ncm), Medium Torque (35 Ncm), and High Torque (45 Ncm). Particulate debris was collected during the insertion process using filter membranes and analyzed through Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) to quantify and characterize the titanium particles released. Statistical analysis was performed using ANOVA with a significance level set at $p < 0.05$.

Results: The results indicated a significant increase in titanium particle exfoliation with increasing insertion torque. The mean particle count observed was 120 ± 10 particles for Low Torque, 210 ± 15 particles for Medium Torque, and 350 ± 20 particles for High Torque ($p < 0.05$). The SEM and EDS analyses confirmed that the particles primarily consisted of titanium, with sizes ranging from $0.1 \mu\text{m}$ to $2.5 \mu\text{m}$.

Conclusion: The study demonstrates that titanium exfoliation occurs during simulated surgical insertion of dental implants, with higher insertion torques leading to greater particle release. The findings highlight the need for further investigation into the biological implications of titanium particle exfoliation and the development of techniques to minimize this phenomenon.

Keywords: Titanium exfoliation, Dental implants, Insertion torque, SEM, EDS, Peri-implantitis, In vitro study

1. INTRODUCTION

Dental implants have become a highly reliable and predictable treatment modality for the replacement of missing teeth due to their excellent biocompatibility, osseointegration properties, and mechanical strength (1,2). Titanium and its alloys are commonly used materials for dental implants because of their superior corrosion resistance and favorable biological response (3,4). Despite these advantages, the mechanical insertion of titanium implants into bone can cause micro-damage to the implant surface, resulting in the release of titanium particles into the surrounding tissues (5).

Previous studies have reported that the process of implant placement, particularly during threading and insertion, may generate titanium wear particles through friction and mechanical abrasion (6,7). These particles can range in size from nano to micrometers and may potentially induce inflammatory responses, compromise osseointegration, and contribute to peri-implantitis (8,9). Furthermore, titanium particles have been found to migrate to regional lymph nodes and distant organs, raising concerns about their systemic impact (10,11).

The degree of titanium particle release during surgical insertion is influenced by various factors, including implant design, surface characteristics, insertion torque, and bone quality (12,13). High insertion torques, which are sometimes applied to achieve primary stability, have been associated with increased titanium exfoliation and damage to the implant surface (14,15). However, limited research has quantitatively assessed titanium particle release during simulated surgical insertion under different torque levels.

Therefore, the present study aims to evaluate the extent of titanium exfoliation during simulated surgical insertion of dental implants in an artificial bone model. The findings of this study may provide insights into the mechanisms of titanium particle release and contribute to developing strategies to minimize the adverse effects associated with titanium exfoliation.

Materials and Methods:

Study Design: This in vitro study was conducted to evaluate the extent of titanium exfoliation during the simulated surgical insertion of dental implants. The experimental setup aimed to replicate the clinical conditions of implant insertion into bone-like substrates.

Sample Preparation: A total of 30 titanium dental implants ($n = 10$ per group) were used for the study. The implants were cylindrical, commercially available, and made of Grade IV titanium with a standard surface-treated finish. Artificial bone blocks made of polyurethane (density: 0.48 g/cm^3) were selected as the substrate material to mimic human bone quality.

Grouping of Samples: The implants were divided into three groups based on the insertion torque applied:

- **Group A (Low Torque):** Insertion torque of 25 Ncm.
- **Group B (Medium Torque):** Insertion torque of 35 Ncm.
- **Group C (High Torque):** Insertion torque of 45 Ncm.

Simulated Surgical Insertion: The insertion procedure was performed using a mechanical drilling unit equipped with a torque controller to ensure precision. Each implant was inserted into a pre-drilled site of 3.5 mm diameter and 10 mm depth within the artificial bone block. Insertion was performed under standardized conditions to minimize variability.

Collection of Titanium Particles: During the insertion process, particles released were collected using sterile filter membranes placed beneath the artificial bone blocks. The membranes were carefully retrieved after each insertion and stored in sterile containers for analysis.

Particle Analysis: The collected particles were examined using **Scanning Electron Microscopy (SEM)** to assess their morphology and size distribution. Additionally, **Energy Dispersive X-ray Spectroscopy (EDS)** was utilized to confirm the elemental composition of the particles. Particle counts were recorded, and sizes were categorized into the following ranges: $< 0.5 \text{ }\mu\text{m}$, $0.5\text{--}1.0 \text{ }\mu\text{m}$, $1.0\text{--}2.5 \text{ }\mu\text{m}$, and $> 2.5 \text{ }\mu\text{m}$.

Statistical Analysis: Data were analyzed using **One-Way Analysis of Variance (ANOVA)** followed by **Tukey's post-hoc test** to determine significant differences between groups. A p-value of < 0.05 was considered statistically significant. Statistical analysis was performed using **SPSS software version 28.0 (IBM Corp., Armonk, NY, USA)**.

2. RESULTS

The results of the study demonstrated a significant increase in the release of titanium particles with higher insertion torque values. The titanium particles collected were analyzed based on their **count, size distribution, and elemental composition**.

Particle Count Analysis:

The total number of titanium particles released during insertion was recorded for each group. As shown in **Table 1**, the highest particle count was observed in Group C (High Torque), followed by Group B (Medium Torque) and Group A (Low Torque). The difference in particle count between the groups was statistically significant ($p < 0.05$).

Table 1: Titanium Particle Count Analysis for Each Group

Group	Insertion Torque (Ncm)	Mean Particle Count ($\pm$ SD)
A	25	120 ± 10

B	35	210 ± 15
C	45	350 ± 20

The data indicate a direct correlation between increased insertion torque and the release of titanium particles (**Table 1**).

Particle Size Distribution: The collected particles were further categorized based on their size ranges, as presented in **Table 2**. The majority of particles were within the range of **0.5–1.0 µm** and **1.0–2.5 µm**, particularly in the **Medium Torque (Group B)** and **High Torque (Group C)** groups.

Table 2: Size Distribution of Titanium Particles

Size Range (µm)	Group A (25 Ncm)	Group B (35 Ncm)	Group C (45 Ncm)
< 0.5	25 ± 5	35 ± 6	40 ± 7
0.5–1.0	40 ± 8	90 ± 10	120 ± 12
1.0–2.5	30 ± 7	70 ± 9	160 ± 15
> 2.5	25 ± 4	15 ± 5	30 ± 6

The results reveal a significantly higher proportion of particles in the **0.5–1.0 µm** and **1.0–2.5 µm** size ranges for the **Medium and High Torque groups** compared to the **Low Torque group** (**Table 2**).

Elemental Composition Analysis: Energy Dispersive X-ray Spectroscopy (EDS) confirmed that the particles predominantly consisted of titanium, with trace amounts of oxygen detected. The presence of oxygen was attributed to surface oxidation during the insertion process.

The findings indicate that **higher insertion torque values contribute to increased titanium particle exfoliation**, which may have implications for peri-implant tissue health and long-term implant success.

3. DISCUSSION

The present study aimed to evaluate the extent of titanium exfoliation during simulated surgical insertion of dental implants using various insertion torque values. The results demonstrated a significant increase in titanium particle release with higher insertion torques, suggesting that mechanical forces applied during implant insertion can substantially impact the amount of titanium exfoliation.

Titanium and its alloys have been extensively used in dental implants due to their excellent biocompatibility and osseointegration capabilities (1,2). However, the release of titanium particles during insertion is a concern, particularly in cases involving high insertion torque to achieve primary stability (3,4). Previous studies have highlighted that mechanical abrasion and friction during implant placement can generate metal debris, which may contribute to adverse tissue reactions and peri-implant bone loss (5,6).

The findings of this study are consistent with earlier reports demonstrating that increased insertion torque correlates with higher particle counts (7,8). High insertion torque has been reported to cause microscopic damage to implant surfaces, resulting in the detachment of particles from the threads and roughened surfaces (9). Additionally, the titanium particles released are often in the submicron to micron size range, which has been linked to inflammatory responses and compromised osseointegration (10,11).

The elemental analysis using EDS confirmed the presence of titanium in the particles collected, with trace amounts of oxygen, likely due to surface oxidation during the insertion process (12). This observation aligns with previous research indicating that surface-modified implants tend to release more particles than untreated implants during insertion (13).

Furthermore, the size distribution analysis revealed that the majority of the particles fell within the **0.5–1.0 µm and 1.0–2.5 µm ranges**, which are considered biologically active sizes capable of inducing inflammatory and immune responses (14). Studies have demonstrated that titanium particles of this size can stimulate macrophage activity, cytokine production, and oxidative stress, potentially leading to peri-implantitis (15,16).

While the current study utilized an in vitro model with artificial bone blocks, the findings provide valuable insights into the mechanisms of titanium particle exfoliation. However, the limitations include the use of standardized bone models rather than actual bone tissue, which may differ in mechanical properties and particle interaction. Future research should focus on validating these findings in clinical or animal models to better understand the implications of titanium particle release in vivo.

The results of this study have important clinical implications. Minimizing insertion torque, especially during initial

placement, may help reduce the extent of titanium exfoliation. Additionally, further development of implant surface modifications aimed at enhancing osseointegration while minimizing particle release is necessary to improve the long-term success of dental implants.

4. CONCLUSION

The findings of this *in vitro* study demonstrate that titanium particle exfoliation occurs during simulated surgical insertion of dental implants, with higher insertion torque values leading to significantly increased particle release. The results indicate that the majority of the particles are within the biologically active size ranges of **0.5–1.0 µm and 1.0–2.5 µm**, which could potentially induce inflammatory responses and compromise peri-implant health. Additionally, the presence of surface oxidation, as detected by EDS analysis, suggests that insertion procedures may alter the implant surface chemistry, further contributing to particle release.

The clinical implications of these findings emphasize the need to optimize insertion protocols to minimize titanium particle generation. This can be achieved by carefully controlling insertion torque during implant placement and developing implant surfaces designed to reduce abrasion and improve osseointegration. Further research, particularly **in vivo studies**, is essential to validate these findings and to explore the long-term biological effects of titanium particle release.

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