# Microstructure and Microtexture Evolution of Titanium Dental Implants Following Single Direction Torsion

*Mahmoud Elkahly, DDS, BDS, MS [1]* Geoffrey Thompson, DDS, MS [2]*
*Rafael Pacheco, DDS, MDS, Ph.D. [3] Mohamed El-Shewy DDS, MS, MBA [3]*

*[1]PGY-3, Prosthodontics Department, Presenting Author [2] Professor, Department of Restorative Sciences [3] Associate Professor, Department of Restorative Sciences*

**melkahly@augusta.edu*

AUGUSTA UNIVERSITY

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## ABSTRACT

The specific aims of this study are to elucidate the effects of single direction torsion on the microscopic deformation behavior, surface topography, and microstructure of internal connection dental implants. The investigators are unaware of any research that considered microscopic changes to the dental implant surface after placement into a bone analogue or alterations to its microstructure following clinically relevant insertion torque.

## PURPOSE STATEMENT

The purpose of this study was to evaluate the effects of increasing insertion torque on the microstructure and surface characteristics of commercially pure titanium dental implants. Specifically, the study investigated whether higher levels of torsional loading during implant placement result in metallurgical and crystallographic alterations, as well as changes in surface topography.

In addition, two exploratory objectives were included: (1) to assess potential loss of the nanohydroxyapatite (nHA) surface coating by measuring calcium (Ca) and phosphate (P) depletion on implant surfaces using Energy Dispersive Spectroscopy (EDS); and (2) to evaluate elemental transfer from the implant into the surrounding bone analogs by detecting titanium (Ti), calcium (Ca), and phosphate (P) deposition following insertion.

All analyses were qualitative, descriptive, and summative in nature.

## MATERIALS AND METHODS

A total of 28 cold-worked, CP Grade 4 titanium implants (4.3 × 11.5 mm, Unitite, S.I.N., Brazil), with double acid-etching and nanohydroxyapatite (nHA) coating, were placed into Type II cortico-cancellous polyurethane bone blocks (Sawbones®, USA). A fully guided surgical guide was designed using RealGUIDE software (ZimVie, FL) and 3D printed (Form 3B, Formlabs Inc.). Implants were inserted by an experienced surgeon at 30 Ncm (T1), 60 Ncm (T2), and 80 Ncm (T3), with four untorqued controls. Torque was measured using a surgical motor and torque wrench.

Implants were retrieved by fracturing the blocks to preserve single-direction torsion. Six implants per torque group and two controls were embedded in epoxy for metallographic analysis. Grinding, polishing, and final chemo-mechanical polishing were completed by Buehler (USA), and bright field microscopy (Nikon Eclipse MA200) was used to evaluate five key implant regions.

Surface topography was assessed via SEM (JEOL JSM-IT500 HR) on two implants per group and two controls, analyzing five regions (Platform to Apex). Representative samples were photographed using a Nikon Z6II with a 105mm macro lens. Macroscopic nHA coating loss was quantified using OpenCV (Python) with color-based segmentation.

Elemental analysis using EDS evaluated titanium (Ti), calcium (Ca), and phosphate (P) transfer into bone analogs, and coating loss from implant surfaces. Bone samples were sputter-coated with gold-palladium to enhance conductivity.

Implants were donated by S.I.N Implants . The authors declare no conflict of interest.

## RESULTS

As insertion torque increases, implants exhibit progressively greater surface damage and coating loss. At 30 Ncm, surface topography and the nanohydroxyapatite (nHA) coating remain mostly intact. At 60 Ncm, moderate to severe coating loss and surface smoothing occur. At 80 Ncm, extensive nHA delamination and surface flattening was observed. Additionally, the presence of titanium and calcium wear particles increased with torque, indicating greater material degradation at higher insertion forces.

Crystal-level changes including the formation of microcracks, twinning, grain refinement, and signs of plastic deformation were observed in the 60 Ncm group and became more pronounced in the 80 Ncm group.

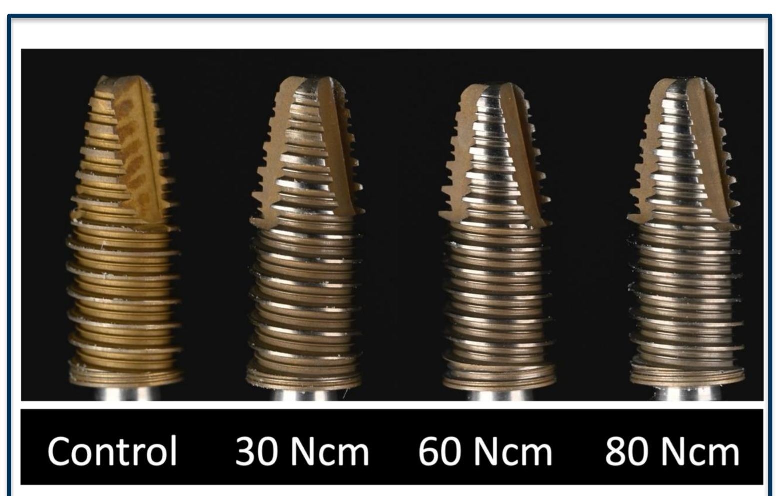



Image illustrating gold surface coating loss post varying torque application.

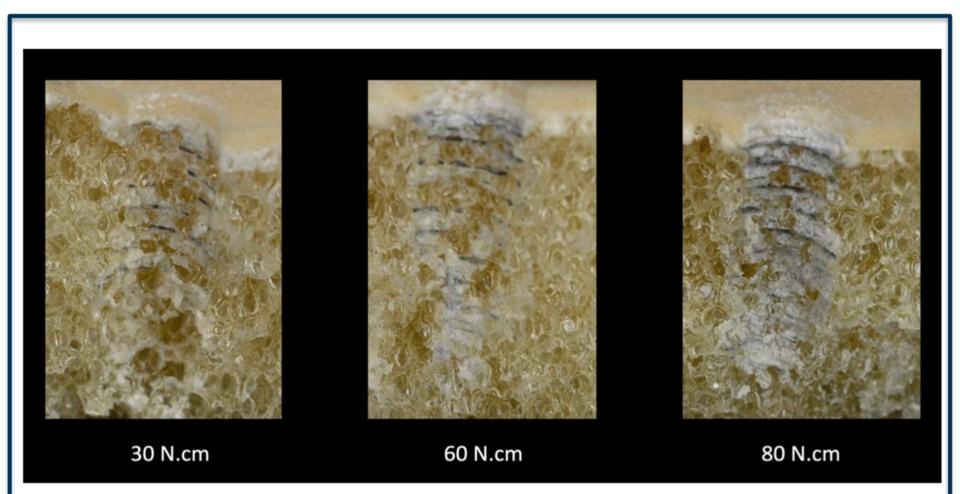
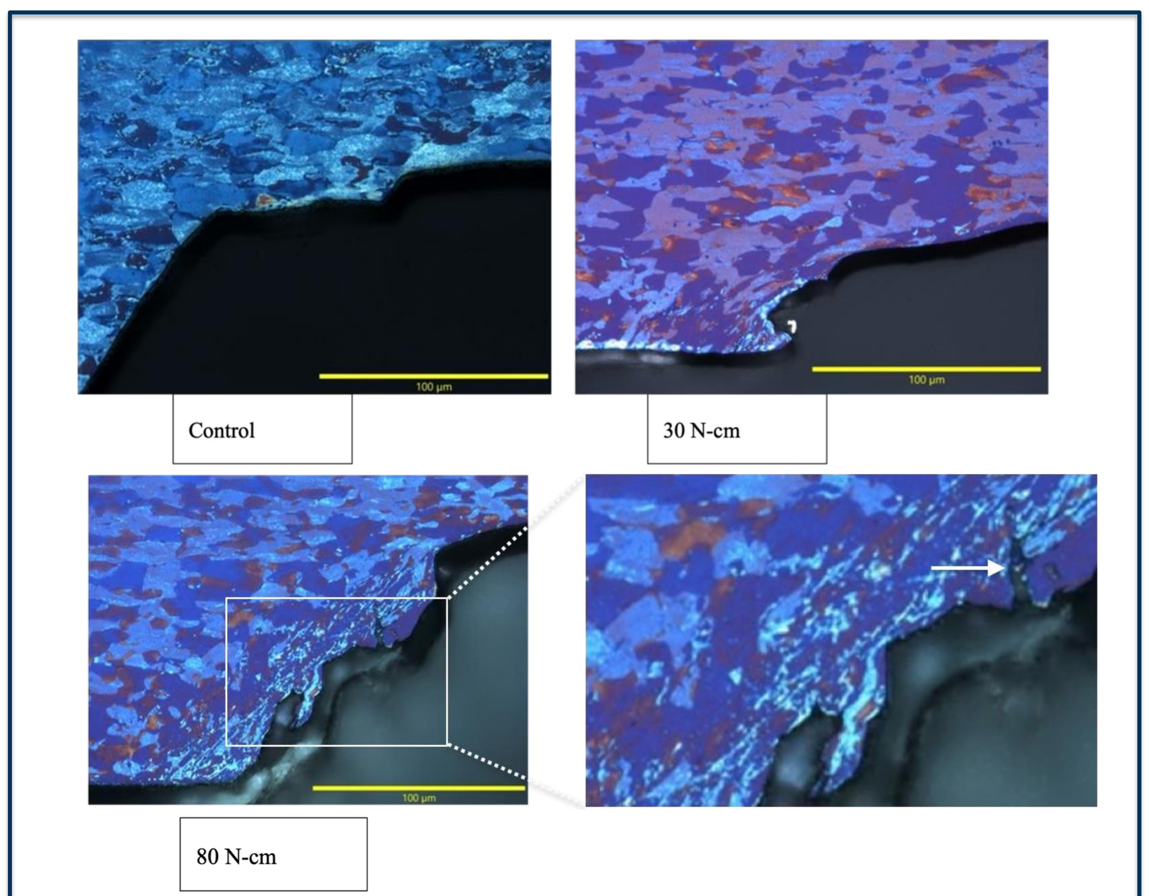
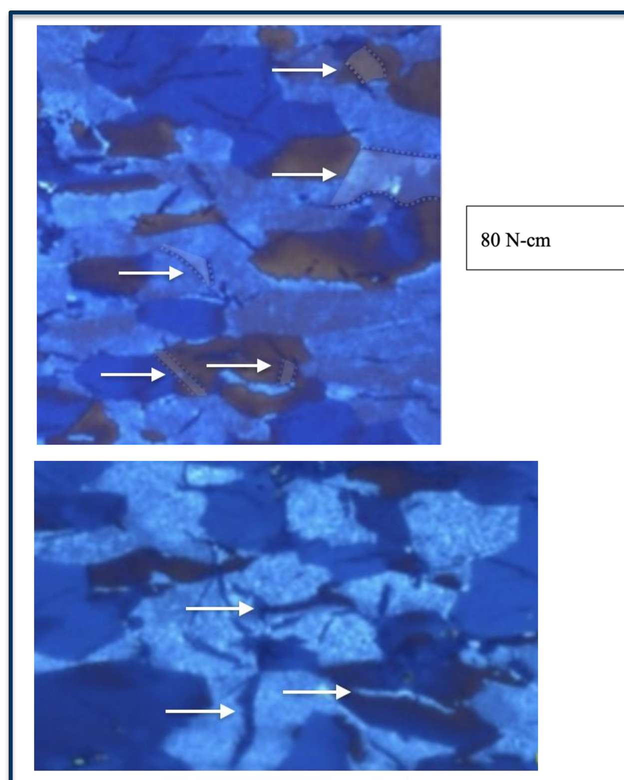


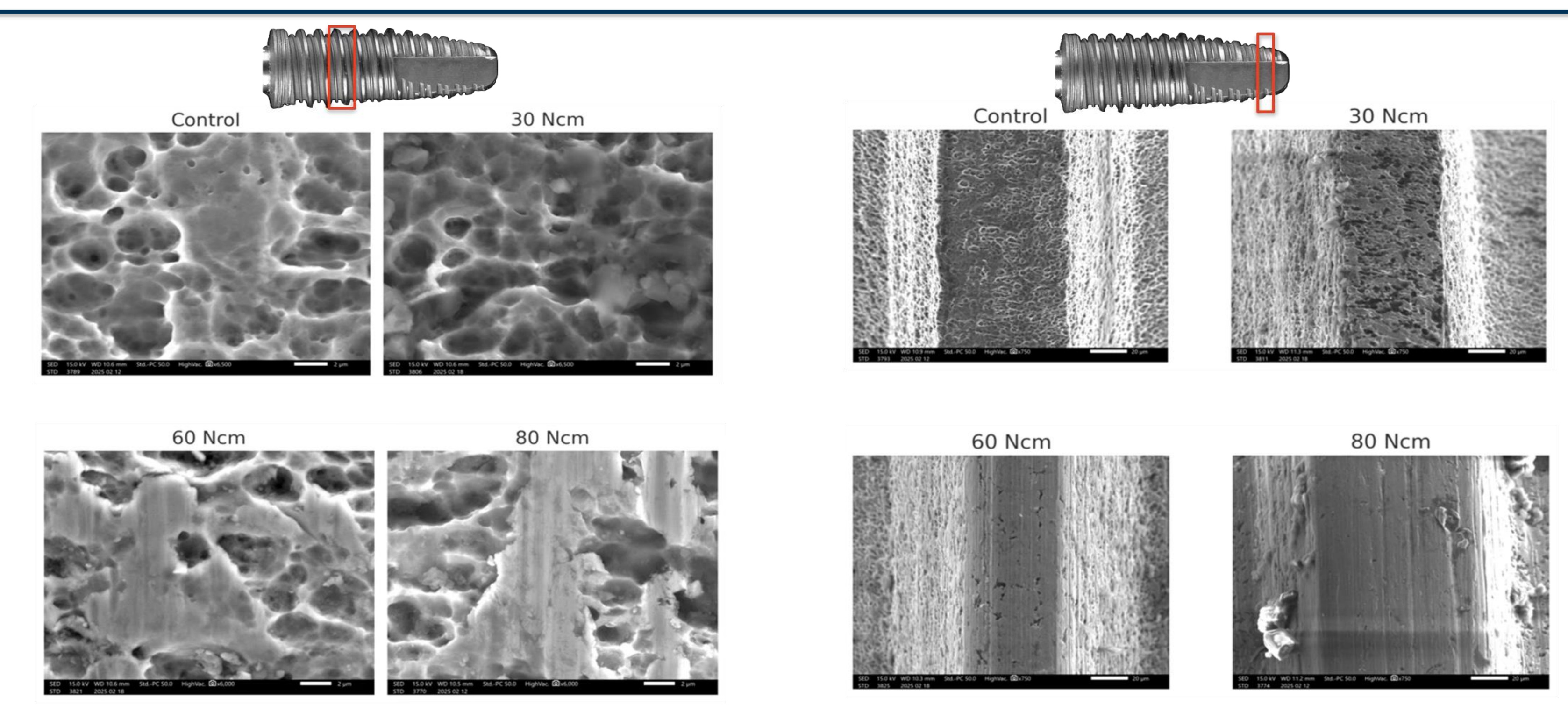

Image illustrating implant-induced debris in sectioned bone substitutes post implant retrieval.




Equiaxed grains observed in the control group. While cracks and grain elongation observed in the 80 Ncm group.




Microcracks and twinned grains were observed in the external coronal third of implants in the 80 Ncm torque group.




SEM of the implant midbody region (x 6,000 magnification).

SEM of the implant apical region (x 750 magnification).

## DISCUSSION

This study demonstrated that increasing insertion torque induces notable microstructural and surface alterations in commercially pure titanium dental implants. Metallographic analysis revealed that torsional loading led to grain refinement, elongation, and twinning, consistent with plastic deformation mechanisms in titanium.

This is in line with the established behavior of titanium under plastic deformation. Twinning can fragment grains and generate new grain boundaries, a process that has been shown to produce finer grains and a more randomized texture in deformed Ti (Chen et al., 2017; Frydrych & Kowalczyk-Gajewska, 2018).

Twinning was minimal at 30 Ncm but became moderate to severe at 60 and 80 Ncm, with microcracks appearing at 60 Ncm and propagating cracks evident at 80 Ncm. High torque also appeared to deform the apical seat of the implant platform, potentially increasing the risk of screw loosening or prosthetic misfit.

Surface analyses showed progressive damage to the implant's topography and nanohydroxyapatite (nHA) coating at higher torque levels. SEM and photographic imaging confirmed coating delamination and smoothing of the microtopography, particularly at 80 Ncm. Linear striations observed in the high torque groups on the implant surface indicating frictional contact during insertion. These findings align with a prior study on mechanical wear (Senna et al., 2015).

Elemental analysis revealed titanium and calcium transfer to the bone analogs at 60 and 80 Ncm, with no detectable transfer at 30 Ncm or in controls. This suggests a torque threshold beyond which surface degradation and debris release occur. Titanium debris has been linked to inflammatory responses, macrophage activation, and potential aseptic osteolysis (Franchi et al., 2004). While our findings support these concerns, the specific amount of debris required to initiate a biological response remains uncertain.

## CONCLUSION

High insertion torque can alter the implant's microstructure at a microscopic level, even in the absence of macroscopically visible damage. The findings of this study indicate that elevated insertion torque influences the as manufactured metallurgical characteristics of commercially pure titanium dental implants.

## REFERENCES & SUPPLEMENTAL IMAGES

References

Supplemental Images