Effects of taper mismatch angle and head topography on modular hip taper contact mechanics

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Introduction

- Total hip arthroplasty (THA) modular junctions are increasingly implicated in adverse local tissue reactions and device failures that lead to revision surgeries[1]
- Micro-motion between modular junction head and stem tapers (**Fig 1A**) is believed to result in fretting corrosion
- Roles of taper mismatch angle and manufactured micro-grooves on head/stem taper mechanics are not clear

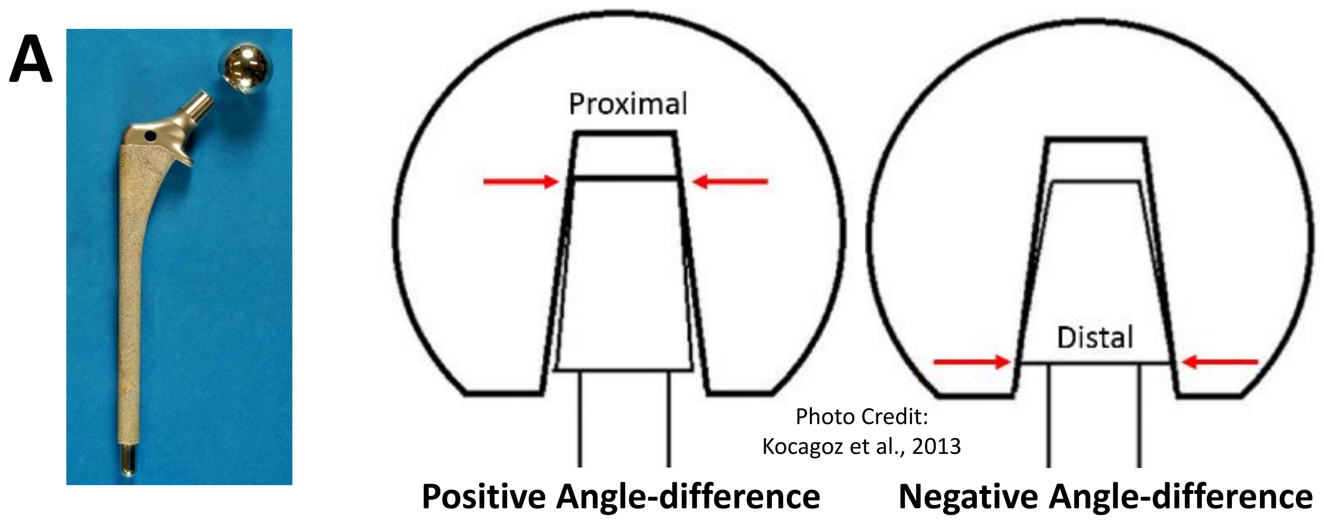


Figure 1: A) Modular total hip replacement; B) Taper mismatch angle leading to proximal (left) or distal (right) contact.

Objective

Employ a novel, micro-grooved finite element hip implant model to determine the effect of taper mismatch angle and head taper finish on modular junction mechanics

Methods

- **FE hip joint model:** 2D axisymmetric stem-head modular junction (**Fig 2**) in Abaqus Standard v6.17
  - Stem: Ti6Al4V (E=119GPa| E_{yield}=795MPa| v=0.30)
    Head: CoCrMo (E=210GPa| E_{yield}=827MPa| v=0.30)[2]
- **Taper mismatch angle:** Mismatch modeled based on median stem and head taper angles[3] (**Fig 1B**)
  - Mismatch: 0 (no mismatch); ±3' (0.05°); ±12' (0.2°)
- **Taper micro-grooves:** Micro-groove height and spacing measured from tapers[3] and modeled as sinusoidal wave
  - Stem: height = 11µm; spacing = 200µm
  - Head: 1) "ideal" flat; 2) height = 2µm, spacing = 25µm

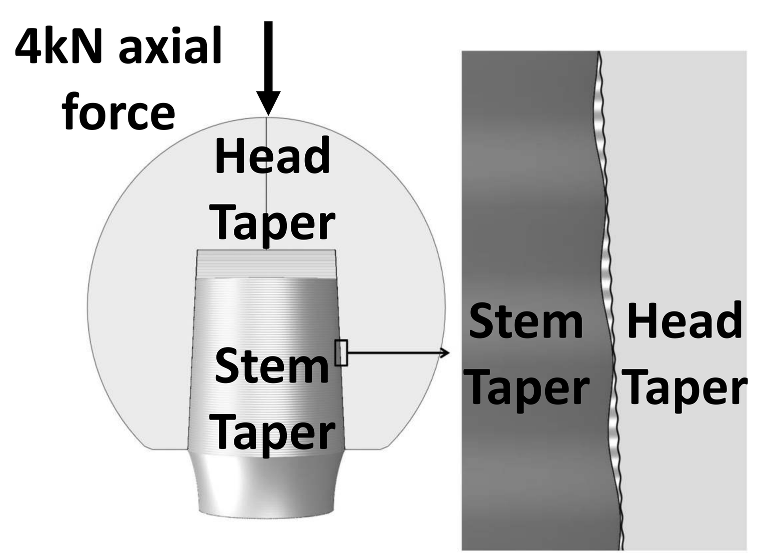
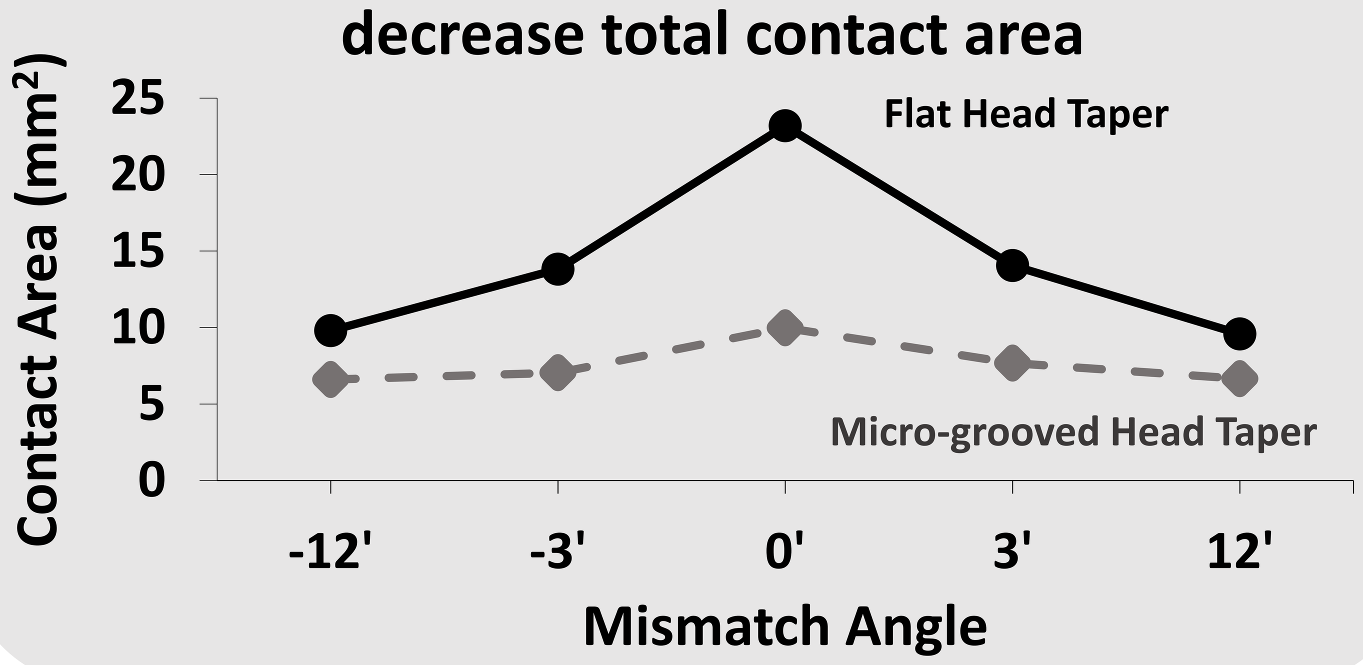


Figure 2: Left: 2D, axisymmetric model under 4kN assembly load; Right: Micro-grooves of head and stem tapers undergoing contact

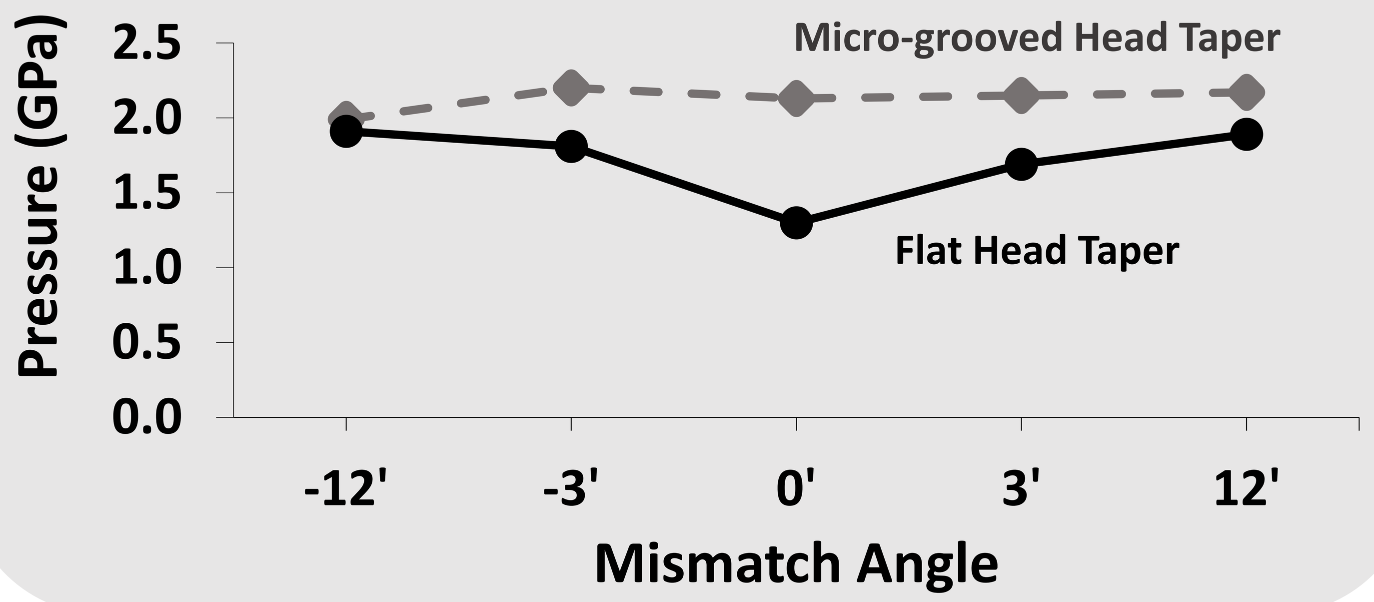
- **Simulation & outcome parameters:** Ten simulations (5 mismatch angles x 2 head taper surface types)
  - Contact mechanics assessed via contact area, pressure, plastic deformation, and percentage of micro-grooves undergoing plasticity

Results

Taper mismatch and head taper micro-grooves decrease total contact area



Head taper micro-grooves lead to high contact pressures regardless of mismatch angle



Head taper micro-grooves change modular junction contact mechanics

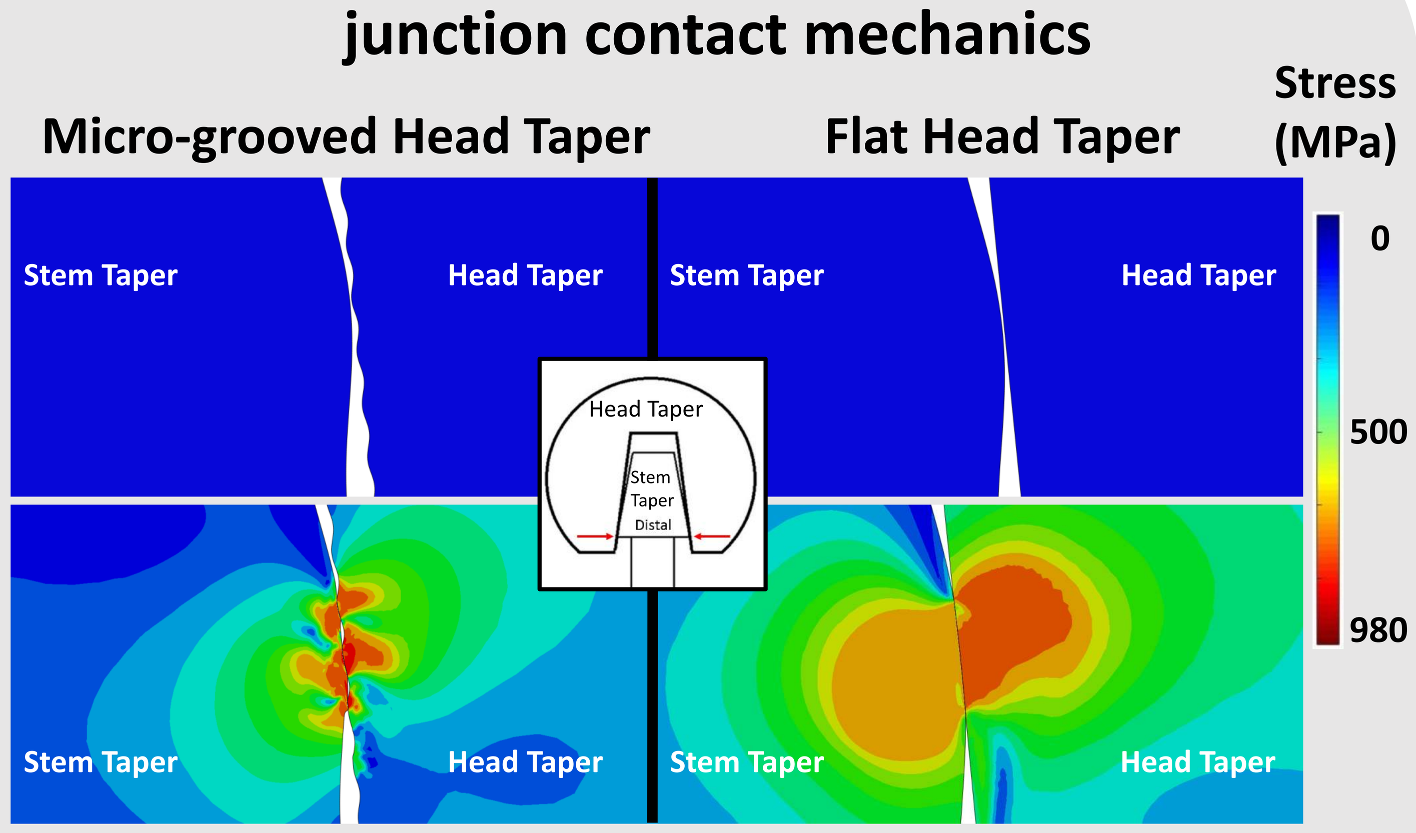
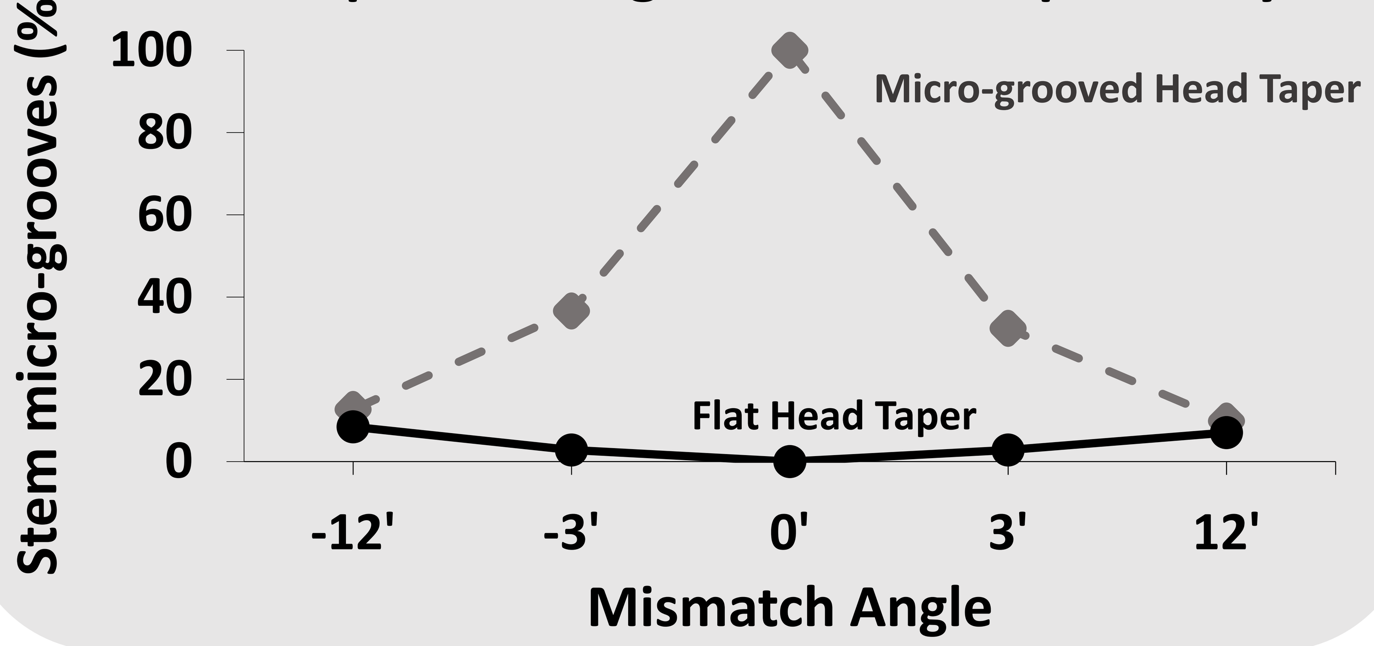


Figure 3. Von Mises stress after assembly of a micro-grooved head taper (Left) and "idealized" flat head taper (Right)

Head taper micro-grooves increase number of stem taper micro-grooves under plasticity



Discussion

Taper mismatch angle has a significant impact on modular junction contact mechanics (**Table 1**)

- Significant reduction in contact area with increasing mismatch—both positive and negative mismatches
- Reduced contact may influence long-term stability[3]

Taper micro-grooves—particularly head taper—affect modular junction contact mechanics (**Fig 3**)

- Plastic deformation only seen in head tapers with micro-grooves; supported by retrieved implants[4]
- Current modeling methods should consider the head and stem taper micro-grooves in future studies

Table 1. Modular junction contact characterization due to taper mismatch angle and head taper surface finish

Head Taper Finish	Taper Mismatch Angle: No Mismatch	Taper Mismatch Angle: Large Mismatch
Flat	• Greatest contact area • Lowest stress • Broad contact region • No plastic deformation	• Decreased contact • Increasing stress • Reduced engagement • Minimal plasticity
Rough	• Moderate contact • High contact stress • Maximal engagement • Greatest number of grooves under plasticity	• Lowest contact area • High contact stress • Minimal engagement • High plastic deformation • Low # grooves deforming

- Which combination of taper mismatch and surface finish improves long-term modular junction stability?
  - Conflicting evidence whether "smoother" or "rougher" surfaces lead to improved implant life[3-5]
  - Micro-grooves provide more "forgiving" mechanism with increasing taper mismatch angles
- Future studies will conduct large-scale parametric analysis to identify most important parameters

Significance

A novel, micro-grooved finite element hip implant model identified unique contact mechanics at the modular junction due to taper mismatch angle and head taper surface finish. Realistic head taper surfaces are necessary to simulate damage patterns seen in-vivo.

Acknowledgements

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References

[1] Hussey and McGrory, J Arthroplasty, 2017
[2] Lundberg et al., ASTM STP 1591, 2016 p59-82
[3] Pourzal et al., CORR, 2016
[4] Arnholt et al., ASTM STP 159, 2016 p99-112
[5] Hall et al., J Biomed Mater Res B Appl Biomater, 2018