# Subject-Specific Curved-Beam Modelling of the Proximal Femur: The Relationship between Femoral Geometry and Stresses during Lateral Falls on the Hip

UNIVERSITY OF WATERLOO KINESIOLOGY

Steven P. Pretty, Iris C. Levine & Andrew C. Laing

Department of Kinesiology, University of Waterloo, ON, Canada

INJURY BIOMECHANICS AND AGING LAB

Coupling experimental impact data and subject specific beam models provides insight into mechanistic pathways supporting epidemiological fracture risk findings

## INTRODUCTION

**Background:** Clinical femoral geometry elements have been linked to epidemiological hip fracture risk [1]. The underlying mechanisms have been attributed to fracture strength [1], however, **geometry also influences peak stress magnitude and location** [2].

Wider neck shaft angle is associated with increased fracture risk but has not been demonstrated to influence fracture strength experimentally [3]. From a mechanistic perspective, the proximal femur will fracture when the load at a given cross-section exceeds strength. Thus, consideration of both applied loads and tissue strength may inform the mechanistic pathway through which geometry elements influence fracture risk.

Femoral geometry elements have been found to influence the distribution of loads over the skin surface during simulated falls [4], but tissue level loading has not been investigated.

**Purpose:** The primary goal of this project was to determine whether **clinical femoral geometry elements**, previously related to femur fracture tolerance, **correlate with stress based fracture risk indices** (FRI) during a simulated lateral fall.

**Hypotheses:** We hypothesized that: 1) FRI and stress at the narrow neck would positively correlate with neck shaft angle and femoral neck axis length; and 2) FRI at each cross-section would negatively correlate with corresponding region width.

## METHODS

**Participants:** Seventeen young healthy females consented to participate in this study. Participant characteristics are presented in Table 1.

Table 1: Mean (SD) Participant Characteristics

| Age (years) | Mass (kg) | Height (m) | BMI (kg/m$^2$) |
|---|---|---|---|
| 24.4 (3.2) | 64.1 (10.5) | 1.66 (0.06) | 23.4 (3.9) |

**Fall Simulations:** Lateral falls were simulated using a pelvis-release protocol (Figure 1). The participant's hip was isolated in a thin nylon sling and raised to a height of 5 cm. The sling was released using an electromagnet and the lateral aspect of the hip impacted a force plate. Peak force (FI) during the impact was extracted and averaged across three trials.

Figure 1 : Pelvis Release Protocol

**Geometry Extraction:** Right hip dual-energy x-ray radiographs (Hologic Discovery QDR) were analyzed to determine: femoral neck width (NW), inter-trochanteric width (TW), femoral neck axis length (FNAL), neck-shaft angle (NSA), and inter-trochanteric region cortex width (ITC) (Figure 2 Left).

## METHODS

**Model Development:** Subject-specific curved-beam proximal femur models were generated [5]. Maximum stress and FRI were determined for two cross-sections: narrow neck (NN) and intertrochanteric (IT). Two loading conditions were simulated, corresponding with a lateral fall onto the hip (Figure 2 Right): 1) impact vector directly perpendicular to the femoral shaft (PERP) and 2) coincident with the intertrochanteric cross section (CO_IT).

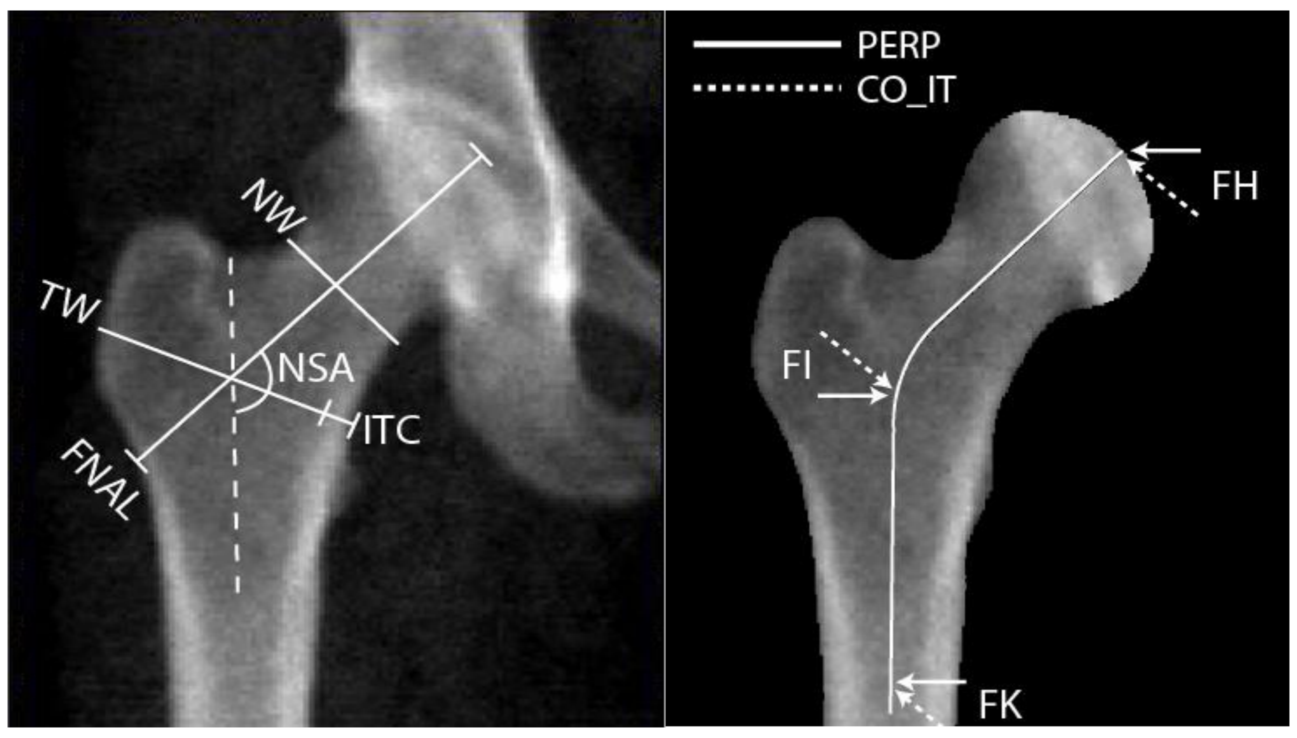


Figure 2: (Left) Femoral Geometry; (Right) Loading Conditions

## RESULTS

**Narrow Neck:** NSA was positively correlated with FRI (r>.526; p<.015) and stress (r>.721; p<.001, Figure 3) for both loading conditions. NW was negatively correlated with FRI for PERP (r=.434; p=.041) and approached significance for CO_IT (r=358; p=.079). TW was negatively correlated with stress for both loading conditions (r<-.581; p<.05).

**Intertrochanteric:** ITC was negatively correlated with FRI (r<-.734; p<.010) and stress (r<-.691; p<.01) for both loading conditions.

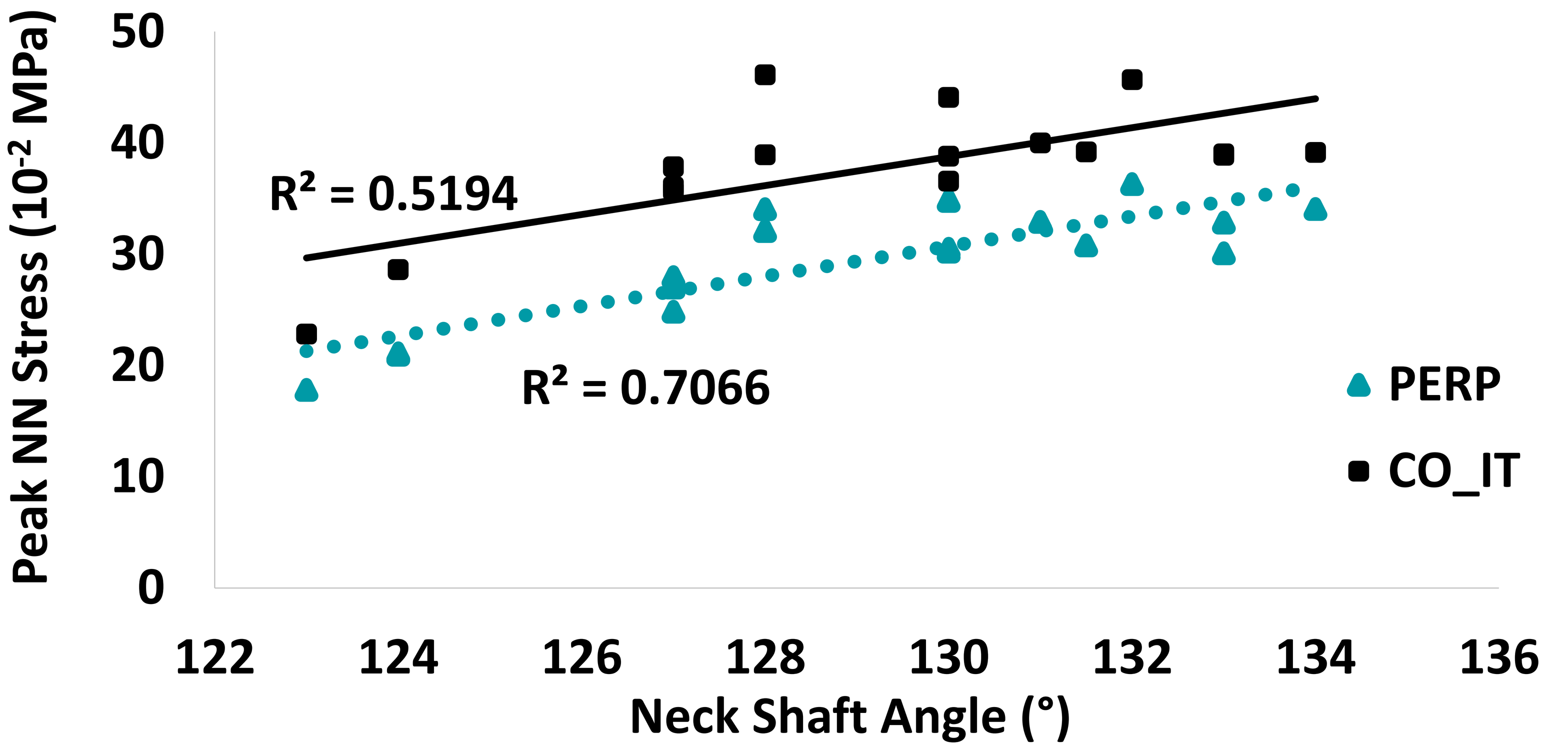


Figure 3 : Wider NSA is associated with greater NN stress

## DISCUSSION & CONCLUSIONS

**Interpretation:** This study demonstrated that elements of femoral geometry are related to fracture risk and stress using a simple curved-beam modeling approach. Wider NSA was associated with increased FRI and stress, supporting previous epidemiological studies linking wider NSA with increased fracture risk [3]. These findings, coupled with experimental fracture testing [3], suggest NSA likely influences fracture risk through applied loads rather than strength.

**Future Directions:** Inclusion of detailed experimental loading conditions (anatomical point of application, line of action) and potential soft tissue interactions may provide additional insight into the influence of femoral geometry on stress generation and fracture risk in the proximal femur.

**Conclusion:** Overall, our approach was novel through the coupling of subject-specific proximal femur beam models and experimental impact data, providing insight into fracture risk from a load application and stress generation perspective. The relationships between elements of femoral geometry and fracture risk observed in this study should be considered in the development of personalized protective equipment, such as hip protectors.

## REFERENCES

[1] Pulkkinen (2010). Osteo Int (21), 1269-76.
[2] Schileo (2008). J Biomech (41), 356-67.
[3] Gnudi (2012). B J Radiol (85), 467-473.
[4] Pretty (2017). STF Int Conference.
[5] Yang (2009). JBMR(24), 33-42.

## ACKNOWLEDGEMENTS

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