Soft Tissue Force Attenuation and Redistribution during Lateral Hip Impacts

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Coupling in-vitro and in-vivo approaches to predict the effect of soft tissue thickness on femoral neck force

Introduction

- Increased thickness of the soft tissues over the hip is associated with reduced fracture risk, likely due to impact attenuation [1].
- Quantitative relationships between soft tissue thickness and impact force have been limited to the skin-surface (rather than the underlying femur) or developed using mechanical testing systems which lack biological variance.

Objectives

1. Quantify relationships between skin-surface force distributions and peak femoral neck forces in-vitro.
2. Utilize these relationships to investigate the effect of soft tissue thickness on peak femoral neck forces during in-vivo fall simulations.

Methods

In-Vitro Tissue Testing

- Fresh trochanteric soft tissue samples were extracted from eleven cadaveric donors and affixed to a surrogate pelvis-drop tower system.
- Impacts were performed at 2 m/s onto a pressure plate.
- Peak force at the femoral neck and in circular regions centered over the greater trochanter were extracted.

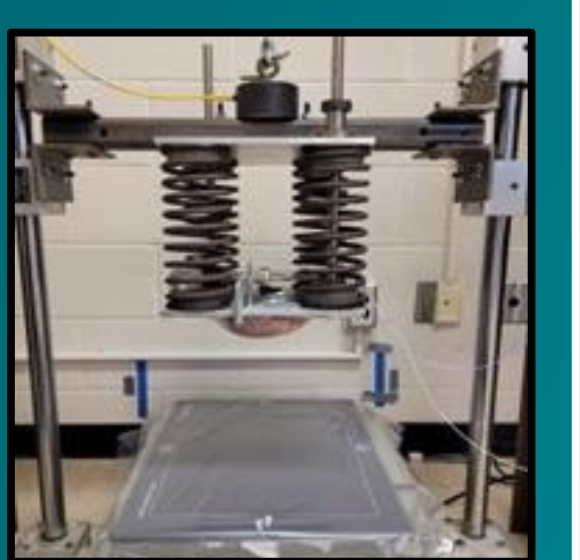


Figure 1: Biofidelic surrogate pelvis with cadaveric soft tissue covering.

In-Vivo Fall Simulations

- Pelvis release experiments were performed by forty young adults at a velocity of 1 m/s onto a pressure plate.
- Peak force in circular regions centered over the greater trochanter were extracted.
- Soft tissue thickness was assessed via ultrasound

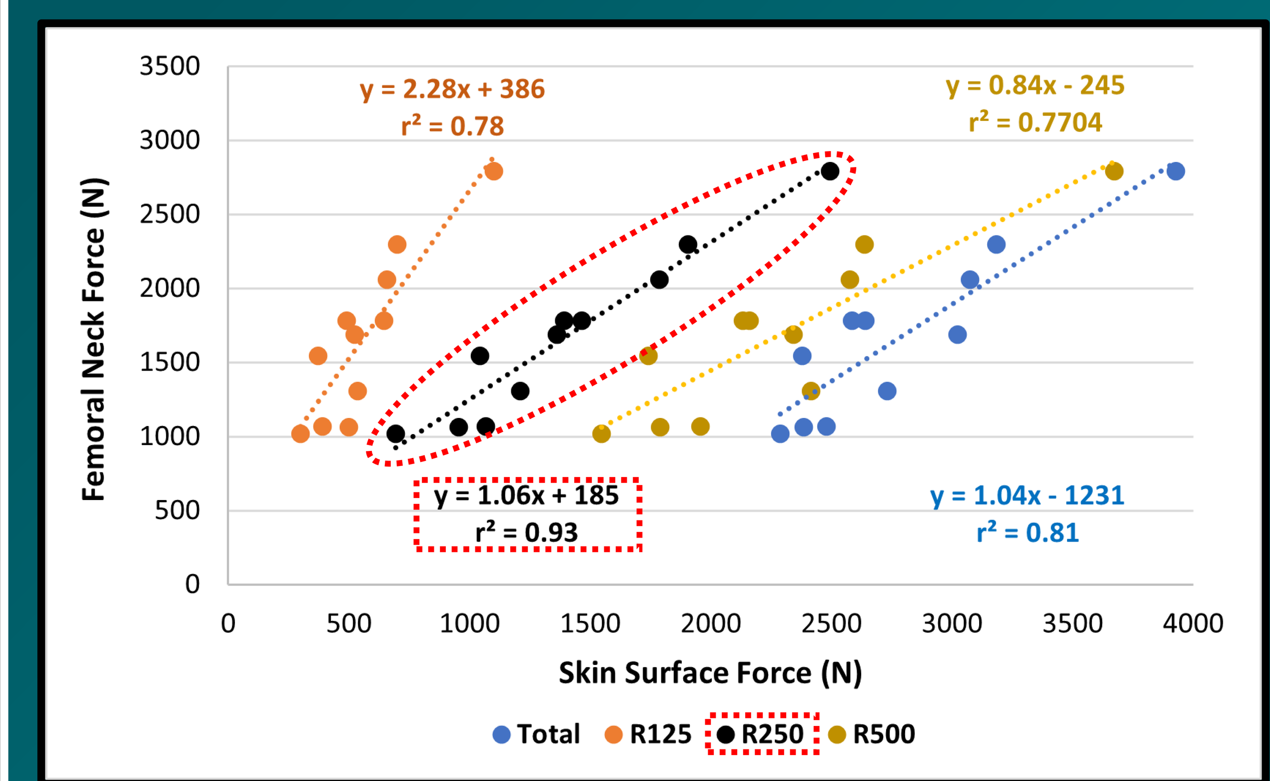
Figure 2: Pelvis release experiment onto a pressure plate (same system utilized during in-vitro testing). Anatomical alignment was performed via rigid body kinematics.

Combined Analysis

- Linear regressions were used to determine relationships between skin-surface impact force distributions and peak femoral neck force during in-vitro testing.
- The strongest in-vitro relationship was utilized to estimate peak femoral neck force from skin-surface impact force distributions during in-vivo falls.
- Linear regression was used to investigate the relationship between soft tissue thickness and predicted peak femoral neck force.

Results

In-Vitro Tissue Testing



- Force applied in a r = 2.5 cm circular region centered over the greater trochanter was the best predictor of femoral neck force (Figure 3: Black with red border), explaining 12.5% more variance than total force.

Figure 3: Relationships between peak femoral neck force and skin-surface impact force distributions:
- Total = All force applied to plate.
- R125, R250, & R500 = Force in circular regions centered over the greater trochanter (radii reported in mm).

In-Vivo Fall Simulations

- No relationship between soft tissue thickness and total skin-surface impact force (Figure 4: Red) was observed.
- Soft tissue thickness was correlated with metrics (R250, & R500) of skin-surface force distribution.
- A 1 cm increase in soft tissue thickness was associated with a 208 N reduction in estimated femoral neck force (Figure 4: Black).

Figure 4: Relationships between soft tissue thickness and peak impact force at the skin-surface and femoral neck.

Conclusions

- This study combined in-vitro and in-vivo approaches to provide novel insights into the relationships between skin-surface and underlying femoral neck forces.
- The in-vitro testing results support previous research [2], which hypothesized differences in skin-surface force distributions would influence femoral neck loading.
  - In contrast, the most relevant region (R250) is smaller than hypothesized [2].
- During in-vivo fall simulations, soft tissue thickness was not found to reduce total impact force. Implementing the relationship between skin-surface force distributions and femoral neck force provided mechanistic support for the protective role of increased soft tissue thickness.
  - The magnitude of force attenuation per unit thickness was ~ 30% of previously reported in-vitro values [1].
- These findings have applications in clinical screening models and in the development of more effective protective devices (ex. hip protectors).
- Future research will aim to computationally model the trochanteric soft tissues to evaluate the combined effects of thickness and material properties on impact force attenuation and transmission.

References:

[1] Robinovitch et al., 1995. J Orthop Res. 13 (6): 956 - 962. [2] Pretty et al., 2021. J Biomech. 127 (11): 110679.

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