Soft Tissue Force Attenuation and Redistribution During Lateral Hip Impacts

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Introduction:

Increased trochanteric soft tissue thickness (TSTT) over the proximal femur is associated with reduced hip fracture risk [1]. The protective effect of these tissues is attributed to increased impact force attenuation and redistribution during falls; however, quantitative relationships between these variables have been limited to the skin surface (rather than the underlying femur) or developed using mechanical testing systems which lack biological variance. The objectives of this study were two-fold: 1) investigate the relationship between skin-surface force distributions and underlying femoral neck impact force in-vitro; and 2) utilize these relationships to investigate the effect of TSTT on femoral neck impact force during in-vivo falling trials.

Methods:

Cadaveric tissue testing: Fresh trochanteric soft tissue samples (15x15 cm; TSTT=1.04–4.57 cm) were extracted from eleven post-mortem human donors. The tissues were affixed to a surrogate pelvis including a composite femur instrumented with a femoral neck load cell. Using a drop tower, each soft tissue-surrogate pelvis system was released onto a rigid pressure plate at a clinically-relevant 2 m/s impact velocity. At the instant of peak femoral neck force, the skin-surface pressure in circular regions (r = 1.25, 2.50, and 5.00 cm) centered over the greater trochanter was spatially integrated to assess load distribution.

In-vivo fall simulations: Forty young adults (TSTT=1.45–7.01 cm) completed lateral pelvis-release experiments onto the pressure plate with a 1 m/s impact velocity. Peak force distribution was assessed consistent with cadaveric testing, utilizing the kinematics of the impacting thigh for spatial alignment with the greater trochanter.

Results:

During cadaveric testing, a 1 cm increase in TSTT was associated with 483 and 399 N reductions in femoral neck (r^2 = 0.85) and total skin-surface impact force (r^2 = 0.78), respectively. The increased reduction in femoral neck force per unit TSTT appears to be driven, in part, by a redistribution of force peripherally away from the greater trochanter. Skin-surface force directed through a 2.5 cm circular-region centered over the greater trochanter was the strongest predictor of peak femoral neck force (r^2 = 0.93), explaining an additional 13% of the variance compared to total skin-surface impact force.

During in-vivo fall simulations, TSTT was not associated with total skin-surface impact force, likely due to mass-driven increases in impact energy with increasing TSTT (Figure 1). Utilizing the relationship between skin-surface force distribution (i.e., force in the 2.5 cm circular-region) and femoral neck force extracted from cadaveric testing, predicted peak femoral neck force was reduced 176 N per 1 cm increase in TSTT (r^2 = 0.43).

Discussion and Conclusions:

This study combines novel in-vivo and in-vitro approaches to provide insights into the relationships between skin-surface and underlying femoral neck loading and has implications for clinical screening models and the design of impact attenuating devices. This data is being coupled with subject-specific femur models to gain additional insights into the influence of TSTT on femoral neck stresses and fracture risk. Future work will computationally model the trochanteric soft tissues to evaluate the combined effects of thickness and material properties on impact force attenuation and transmission.

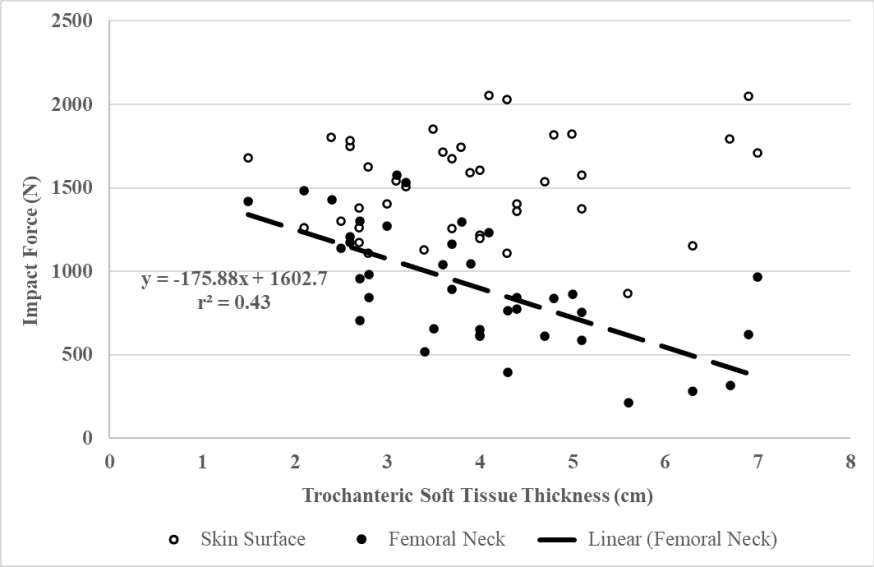

Figure 1: Influence of trochanteric soft tissue thickness (TSTT) on peak skin-surface (no-fill) and femoral neck (solid-fill) forces during in-vivo fall simulations. Peak femoral neck force was estimated from the spatially integrated skin-surface force in a 2.5 cm circular region centered over the greater trochanter, using the relationship established during the in-vitro impact testing of cadaveric soft tissue pads [Femoral neck force (N) = 1.0643 * Skin-surface force (r = 2.5cm) (N) + 184.83].

References:

[1] Leng et al., 2022. *Int Orthop.* 46 (12) :2963 – 2969.