INTRODUCTION

Pelvic fractures occur commonly in side impact automotive crashes (Gokcen et al., 1994). Women are more frequently injured (Lewis et al., 1996), leading automotive researchers to re-focus on women’s safety in side impacts. There is, however, a paucity of biomechanical data for the human female pelvis with the currently accepted fracture tolerance of 4.26 kN based upon extrapolations from impacts on male and female cadavers (Cesari & Ramet, 1982).

Previously, we observed a linear correlation between fracture load and total hip bone mineral density (BMD) in drop tower tests of isolated bone-ligament pelvic structures (Beason et al., 2003). The purpose of the present study was to investigate the influence of trochanteric soft tissues on pelvic fracture measures in more realistic lateral impact experiments. It was hypothesized that intact specimens would fracture at increased force and compression levels as compared to isolated pelvic bones, but would display a similar linear correlation with BMD.

METHODS

Sixteen lateral impacts were conducted on eight fresh-frozen lower torsos (L4 to proximal femurs, hereafter referred to as ‘pelves”) from female cadavers (age 76 ± 10 years). Total hip BMD of the left hip was assessed via dual-energy X-ray absorptiometry (QDR 4500, Hologic Inc., Waltham, MA).

Lateral impacts, centered at the left greater trochanter, were performed using a linear impactor (VIA Systems, Brighton, MI), which employed a pneumatic cylinder to accelerate a 22.1-kg impact mass to the desired impact velocity. The thawed pelves were placed in a custom seat with contralateral support, which allowed lateral translation. An axial preload (~60% body weight) was applied to the vertebral column to simulate upper body weight. The weight of the seat was adjusted to account for the absent body mass.

The first six specimens were impacted at a velocity of 3.33 ± 0.04 m/s. No fractures were observed in subsequent x-rays, so the pelves were struck again at a higher velocity (6.44 ± 0.22 m/s), which induced fracture in each case. Two additional pelves were impacted at an intermediate velocity, 5.01 ± 0.02 m/s to achieve overlapping fracture/no fracture outcomes in order to perform logistic regression analysis. One pelvis fractured at this impact speed. The second pelvis was impacted at 6.4 m/s, and then again at 8.3 m/s, at which point it also fractured. Computed tomography (CT) scans (LightSpeed QX/i, GE Medical Systems, Milwaukee, WI) were examined to classify pelvic ring and/or acetabular fractures.

Force data, \( F(t) \), were obtained through using a uniaxial load cell in series with the impacting mass and striker. The inertially compensated force (Bouquet et al., 1994) was filtered according to SAE J211 (SAE, 2000). The impulse, \( I \), defined as the integral of \( F(t) \cdot dt \) was also computed. A 1-kHz infrared camera (MCU1000, Qualysis Inc., Glastonbury, CT) captured motion of reflective markers attached to the impactor and seat to calculate pelvic compression, \( C(t) \), and the maximum viscous response, \((VC)_{\text{max}}\), where \( V(t) \) = velocity of the impact mass.

\( F_{\text{max}} \), \( I \), \( C_{\text{max}} \) and \((VC)_{\text{max}}\) were analyzed using linear regression to test for correlation with BMD. Logistic regression was used to determine a 25% probability of pelvic fracture for each parameter.
RESULTS

Fractures were located predominantly in the areas of the pubic rami and acetabulum, consistent with those observed in automotive side impacts (e.g., Lewis et al., 1996). The average force to fracture was 4.4 ± 0.95 kN, a 89% increase over the 2.33 ± 0.90 kN average calculated using female data only from Beason et al. (2003). Linear regression showed that as total hip BMD increased, the force to fracture also increased. The regression is shown, along with female data from Beason et al. (2003), in Figure 1. Main effects ANCOVA revealed that the slopes were similar and the intercepts were significantly different (p < 0.005). \( C_{\text{max}} \) and \( (VC)_{\text{max}} \) each demonstrated a negative relationship with BMD, which were not significant (p > 0.1). Impulse displayed no correlation with BMD.

Logistic regression analysis (Figure 2) revealed fracture tolerances (at 25% probability) of 2.99 kN and 90.7 N-s for peak load and impulse, respectively. The 25% tolerance values for \( C(t) \) and \( (VC)_{\text{max}} \) were 12.54% and 0.27 m/s, respectively.

DISCUSSION

The results of this study indicated that fracture force best correlated with total hip BMD of intact cadaver pelves. As hypothesized, the inclusion of soft tissues around the bony pelvis resulted in increased fracture loads as compared to those found for isolated pelvic bones. The current force tolerance of 2.99 kN is lower than the 4.26 kN value extrapolated by Cesari and Ramet (1982) for the 5th percentile female. Our impulse tolerance of 90.7 N-s is within 10% of the 100 N-s tolerance suggested by Cesari et al. (1980). Discrepancies between our results and those of Cesari and co-workers may be attributed to differences in test procedures. While they used full cadavers, both male and female, we used only the lower torso of the female cadaver, inertially compensated by adding mass to the seat. Nevertheless, the present results suggest that older women, especially those with decreased BMD, may be at higher risk for pelvic fracture in automotive side impacts.

REFERENCES


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