Characterizing stiffness change of the proximal femur between quasi-static and dynamic loading in a fall configuration

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Abstract

Hip fracture is a common injury. Previous researchers simulated falls to the side using fixed loading rates in the ranges of 0.7 to 100 mm/s and showed a correlation between loading rate and structural mechanics of the femur. Our goal was to simulate a fall and observe the change in stiffness between the impact and a quasi-static loading scenario. We hypothesized that impact testing would lead to increased bone stiffness.

Seventeen fresh frozen human proximal femora were tested in two ways. First, they were tested quasi-statically, to 50% failure load at 0.5 mm/s. Then they were tested dynamically to failure in a novel fall simulator consisting of: 1) a body mass; 2) a pelvis spring; 3) closed cell foam to simulate trochanteric soft tissue; 4) mass to simulate the lateral pelvis with an impact speed of 3 m/s. Displacement data were collected using high speed video at 9216 frames/s and axial force data were collected at 20 kHz. Stiffness and effective loading rate at the trochanter were calculated as averages from contact to initial failure.

Stiffnesses in the dynamic and quasi-static tests were not significantly higher than in the quasi-static test (paired t-test $p=0.12$). A decreased stiffness in the impact test was correlated to increased loading rate ($r2=0.59$). Osteoporosis classification was not related to change in stiffness ($p=0.14$), but higher DXA was correlated to higher failure load ($p<0.001$, $r2=0.35$).

The data do not support the hypothesis that impact tests had a higher stiffness than quasi-static tests. Similar to the first reference we see a trend of increasing stiffness from 0.5 mm/s up to 200 mm/s. However, this is followed by a decreasing stiffness at higher loading rates. Higher rates have not been evaluated before and behavior may be different than extrapolation of the first reference.