Relating Impact Velocity and Loading Rate to Femoral Bone Strength in Biofidelic Simulated Lateral Impacts

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Using fresh frozen human femora, we observed significant associations between loading rate and impact parameters using a biofidelic hip impact simulator.

INTRODUCTION

Fall-related hip fractures are an increasing concern in the older adult population. Costing an estimated 650 million dollars annually in Canada[1], there is a concerted effort to better understand the underlying mechanics of fall related hip fractures to better predict and prevent them

An important aspect of preventing hip fractures is predicting bone strength, yet current predictions are based on constant displacement experiments[2,3]; little is known about the loading rate of the femur during physiologic hip impacts.

The goal of this study was to quantify the **loading rate** of human femora during biofidelic simulated lateral impacts, and ultimately quantify **bone strength**.

METHODS

Impact Testing

Five human cadaveric femora (specimen age range 27-80 years) underwent hip-specific DXA scans to extract femoral neck BMD. Specimens were then placed in a test system (Figure 1) which incorporated physiologically-based pelvic mass and stiffness properties[4], and subjected to simulated lateral impacts at incrementally increasing drop heights until failure occurred (heights selected to create approximate impact velocities of 0.5 m/s to 4.5 m/s, in 0.5 m/s increments).

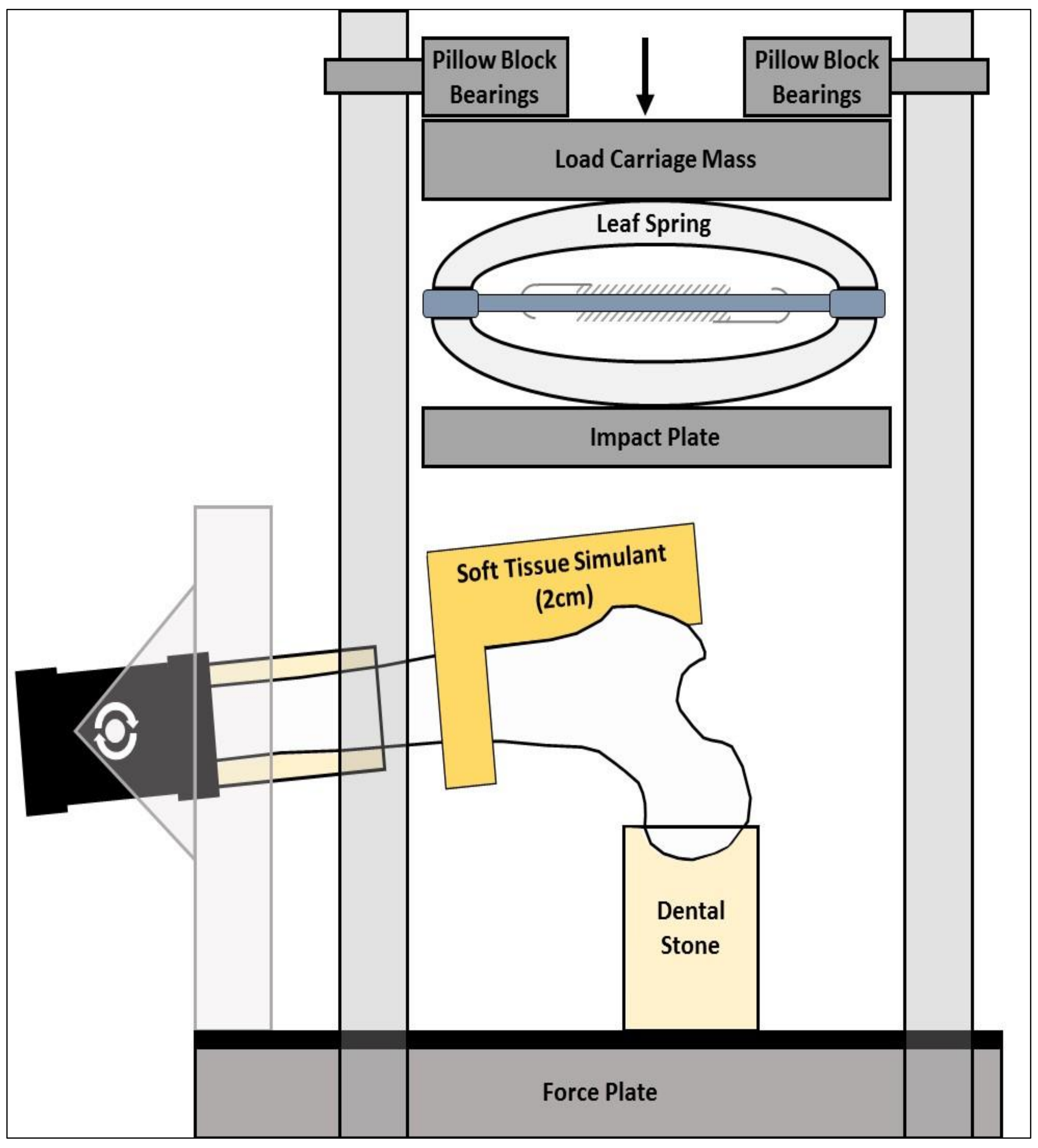

Figure 1: 2D representation of the femur impacting jig. The load carriage system (impact plate, leaf springs, load carriage mass) is attached to pillow block bearings that allow for near-frictionless translation along the vertical guide bars.

METHODS

Data Processing

The primary variables of interest were loading rate, impact energy and peak force; fracture force was defined as the peak force of the trial in which fracture occurred. Specimen-specific and pooled Pearson correlations were computed to investigate the following relationships:

1. Impact velocity and loading rate
2. Impact energy and loading rate
3. Fracture force and BMD
4. Fracture force and age

A non-linear regression model was developed to predict loading rate from impact velocity.

RESULTS

Four of the five specimens fractured during the 4.5 m/s impact condition (actual mean impact velocity = 4.13 m/s, SD = 0.04 m/s). **Mean values** for these specimens included:

- **Fracture force = 4730 N (SD = 468 N)**
- **Loading rate = 103.4 kN/s (SD = 9.3 kN/s)**
- **Areal BMD = 0.691 g/cm^2 (SD = 0.068 g/cm^2)**

One specimen fractured during the 1 m/s condition, with a fracture force of 1804 N and a loading rate of 69.6 kN/s (BMD = 0.513 g/cm^2).

Pearson correlation results are presented in Table 1 and Table 2.

Table 1: Specimen specific and pooled correlation results between loading rate and impact velocity, as well as loading rate and impact energy. Significant correlations (p<0.05) are bold.

Loading Rate	*Impact Velocity*	*Impact Energy*
Specimen 1	**R^2 = 0.521 (p = 0.018)**	R^2 = 0.355 (p = 0.069)
Specimen 2	**R^2 = 0.752 (p = 0.001)**	**R^2 = 0.589 (p = 0.009)**
Specimen 3	R^2 = 0.227 (p = 0.139)	R^2 = 0.080 (p = 0.399)
Specimen 4	**R^2 = 0.465 (p = 0.030)**	R^2 = 0.274 (p = 0.121)
Pooled	**R^2 = 0.494 (p < 0. 001)**	**R^2 = 0.326 (p <0.001)**

Table 2: Pooled correlation results between fracture force and BMD, as well as fracture force and age. Significant correlations (p<0.05) are bold.

Fracture Force	*BMD*	*Age*
Pooled	**R^2 = 0.876 (p = 0.019)**	R^2 = 0.399 (p = 0.253)

RESULTS

A non-linear regression model was developed to predict loading rate from impact velocity (Figure 2):

$$y = 113700*x/(0.5897+x)) \quad (R^2 = 0.740)$$

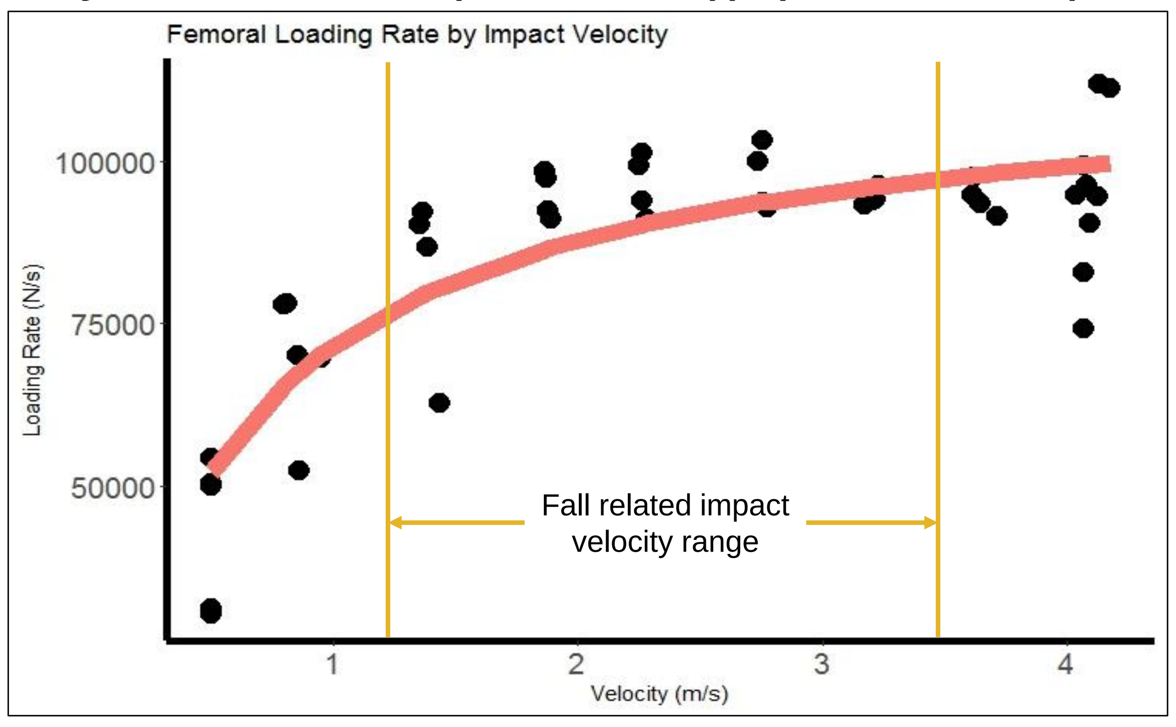

Figure 2: Femur loading rate versus impact velocity. Black dots are individual data points (all specimens, all trials), while the red line is the non-linear regression line of best fit. Orange bars show potential range of fall-related hip impact velocity[5].

DISCUSSION

- Characterized non-linear relationship between impact velocity and loading rate in biofidelic lateral hip impacts
- **Significant positive correlations**
  - **Loading Rate** and **Impact Velocity** (R^2 = 0.494, p < 0.001)
  - **Loading Rate** and **Impact Energy** (R^2 = 0.326, p < 0.001)
  - **Fracture Force** and **BMD**
  - (R^2 = 0.876, p = 0.019)

FUTURE WORK

- Loading Rate/Impact Velocity relationship can be used in future load-controlled mechanical tests of femoral strength
- Expand sample to further characterize relationships these factors and femoral bone strength

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