Differences in Lower Extremity Geometry with Gender, Age, Stature, and BMI

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BACKGROUND

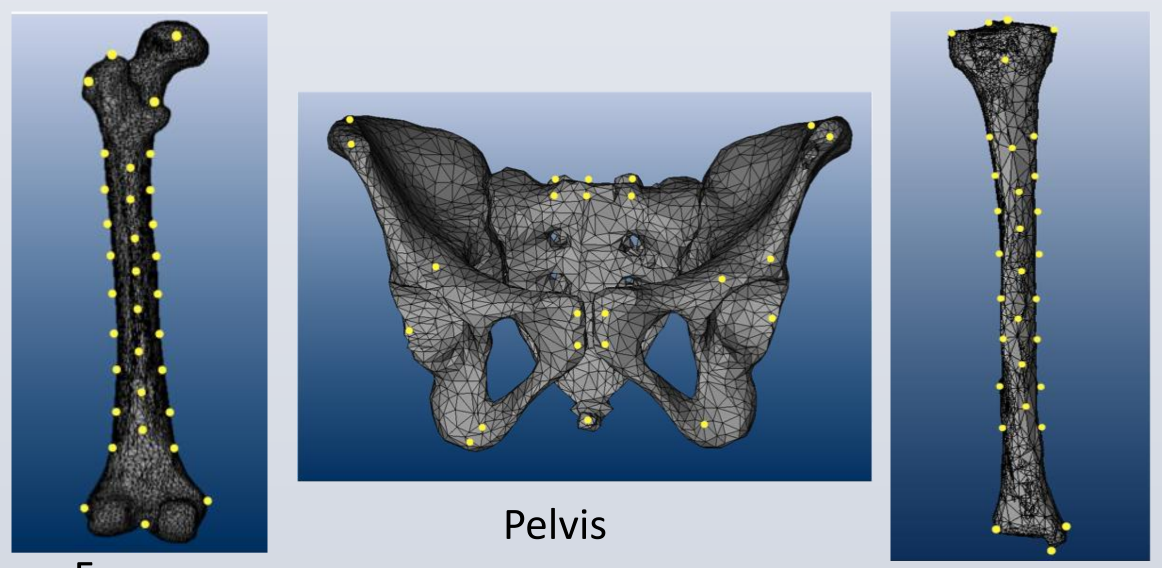
- Improvements in motor-vehicle safety, particularly increased seat belt use and the implementation of airbags, have reduced the risk of injuries to the head, thorax, and abdomen in frontal motor vehicle crashes to the point where the lower extremities are now the body region most likely to sustain clinically significant injury (1).
- Occupant gender, age, and Body Mass Index (BMI) affect the risk of clinically significant lower extremity injuries in such a way that women, older occupants, and occupants with higher BMI are at increased risk (2). The hypothesized biomechanical reasons for these effects are that gender, age, and BMI alter:
  1. Skeletal geometries in the lower extremities and that these differences in geometry affect injury tolerance.
  2. Body size and external shape in a manner that changes restraint forces applied to the lower extremities by seat belts and knee restraints.
  3. Static seated lower extremity posture, which changes knee impact location on the knee restraint and the orientations of the lower extremities during knee loading.
- Developing vehicle restraint systems and other safer vehicle designs that better protect women, older occupants, and higher BMI occupants requires understanding the relative contributions of each of the hypothesized reasons for the age, gender, and BMI effects to the causation of lower extremity injuries.

OBJECTIVE

- To investigate the first hypothesized reason that skeletal geometry is affected by quantifying the differences in lower extremity skeletal geometry with occupant age, gender, stature, and BMI through statistical analyses of skeletal geometry extracted from CT scans.

METHODS

- Extract lower extremity geometry from 100 CT scans of patients approximately equally distributed over both genders with ages 17-89 years, heights 1.5-2 m, and BMIs 15-46 kg/m^2.
- Define surfaces of the tibia, femur, and pelvis using thresholding techniques.
- Record the locations of anatomic landmarks on the tibia, femur, and pelvis surfaces from each subject. Figure 1 shows the femur, pelvis, and tibia with their anatomic landmarks.



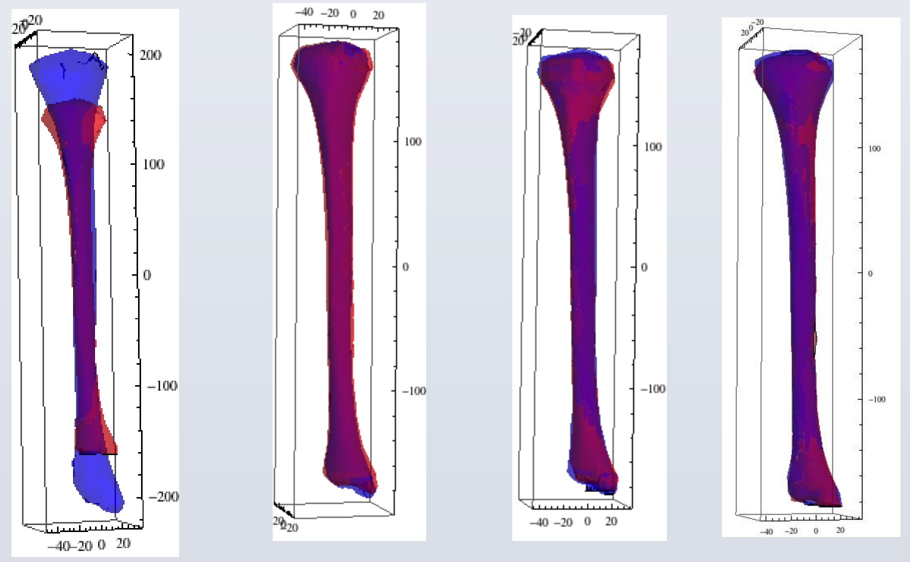
Femur Pelvis Tibia

Figure 1. Lower extremity bone meshes with anatomic landmarks recorded.

- Record corresponding landmark locations on a template mesh (finite element mesh of each bone).
- Morph and project the template mesh to the surfaces of each subject's bones using radial basis functions so that nodal locations of the morphed meshes are at corresponding locations on the surface of each bone following the methods discussed by Li et al. (3).
- Use principal component analysis to characterize the variance in nodal coordinates across the morphed meshes from each subject.
- Use regression on principal component scores to identify the relationships between geometry and age, gender, stature, and BMI.
  - Use model predictions to identify meaningful variance in geometry with the occupant characteristics.

RESULTS

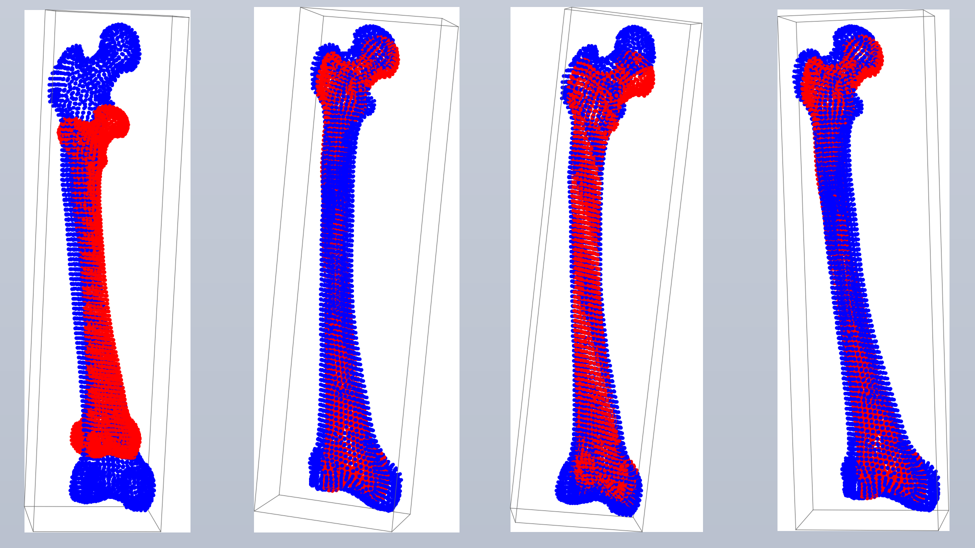
- The only meaningful prediction of tibia size and shape was occupant height. When controlling for all other occupant characteristics, no meaningful differences were seen in tibia shape and size between different genders, ages, and BMIs. Figure 2 shows the tibia geometry predicted for maximum/ male (blue) and minimum/ female (red) height, gender, BMI, and age from the CT dataset.



Height Gender BMI Age

Figure 2. Images showing the effects of varying height, gender, BMI, and age on tibia shape over the ranges present in the CT dataset while holding other parameters constant.

- Femur external shape and size were meaningfully predicted by occupant height, gender, and BMI. Changes in occupant BMI changed the angle between the neck and shaft of the femur. When controlling for other occupant characteristics, occupant age did not predict femur size and shape. Figure 3 shows the femur geometry predicted for maximum/male (blue) and minimum/female (red) height, gender, BMI, and age from the CT dataset.

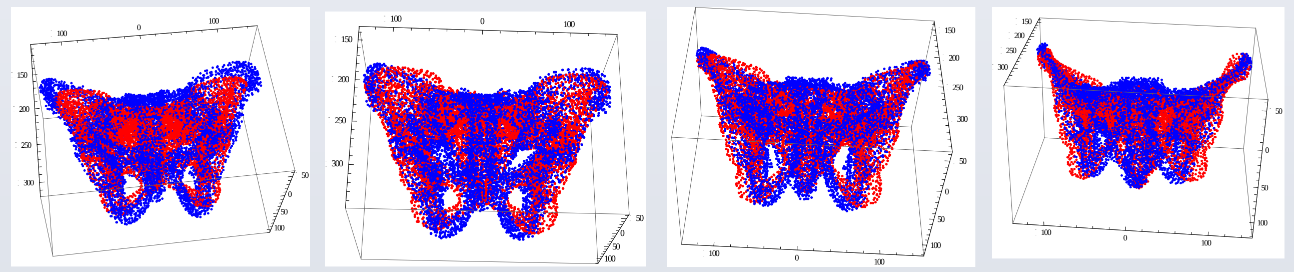


Height Gender BMI Age

Figure 3 Images showing the effects of varying height, gender, BMI, and age on femur shape over the ranges present in the CT dataset while holding other parameters constant.

RESULTS (cont.)

- Pelvis external shape and size were meaningfully predicted by occupant height, BMI, gender, and age. Female pelves are much different in shape than male pelves (e.g. female pelves have wider pelvic inlets and thinner pubic rami). Figure 4 shows the pelvis coordinates predicted for maximum/male (blue) and minimum/ female (red) height, gender, BMI, and age.



Height Gender BMI Age

Figure 4. Images showing the effects of varying height, gender, BMI, and age on pelvis shape over the ranges present in the CT dataset while holding other parameters constant.

CONCLUSIONS AND DISCUSSION

- Pelvis external shape and size were predicted by occupant height, gender, BMI, and age. Femur external shape and size were predicted by occupant height and BMI. Tibia size and external shape were only predicted by occupant height.
- The increase in tibia, femur, and pelvis size from minimum to maximum height was not uniform, which may indicate a gender effect since gender and stature are correlated variables.
- Future work is needed to characterize how bone cross-sectional geometry and the shapes of the foot bones vary with occupant characteristics.

REFERENCES

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