# Lower Limb Bone Shape and Pose Estimation from Sparse Landmarks Using an Articulated Shape Model

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## Introduction

Estimating bone shape and pose from motion-capture landmarks is an essential part of patient-specific biomechanical simulations [1]. Simple length scaling of template models to landmarks cannot account for variations in bone shape. Non-rigid registration using statistical shape models produce more realistic shapes but so far have been restricted to one or two bones [2,3]. We present an articulated statistical shape model for estimating the geometry and pose of five lower limb bones from a sparse set of seven commonly used anatomical landmarks.

## Methods

A combined statistical shape model of the pelvis, femur, patella, tibia, and fibula was created from a training set of 26 lower limb bones segmented from post-mortem CT images. Standard anatomical landmarks were embedded in each bone's atlas mesh as material points and the standard ISB joint and segmental coordinate systems [4] were established on all bones to define articulation. Shape and pose estimation was performed by registering embedded landmarks to target landmarks (LASIS, RASIS, sacral, medial and lateral femoral epicondyles, medial and lateral malleoli). The sum of squared distance between embedded and target landmarks was minimised by optimising principal component weights; rigid-body transformation of the pelvis; femur flexion, rotation, and abduction about the centre of the femoral head aligned with the centre of the acetabulum; and tibial flexion at the knee with a fixed femur-tibia spacing. The patella, without any landmarks, was placed using a fixed offset with respect to the tibial coordinate system.

## Results

Estimation accuracy was validated by a leave-one-out experiment in which for each trial, one training lower limb was left out of the shape model and used to provide the target landmarks. After registration, errors were calculated in terms of the RMS distances between target and registered landmarks, and the RMS distance between the left out and estimated bone surfaces. Mean landmark error was 5.10 mm. Mean surface error was 5.09 mm (pelvis), 4.83 mm (femur), 3.97 mm (tibia/fibula), and 4.74 mm (patella). Figure 1 shows examples of estimated limbs.

## Conclusions

We have developed a method for rapidly estimating patient-specific lower limb bone geometry and pose from seven common motion-capture landmarks using an articulated shape model of the left lower limb. The geometry accuracy is superior to simple scaling methods in literature and comparable to shape model based methods for single bones or joints. The method will be implemented as an open-source tool for community use and testing (see [add link to simtk site or map github repo]).

## References

[1] Cleather, D. J., & Bull, A. M. (2012). Journal of Engineering in Medicine, 226, 133 –145.
[2] Rajamani, K. T., *et al* (2007). Medical Image Analysis, 11(2), 99–109.
[3] Zhang, J., *et al*. (2014). Biomedical Simulation (pp. 182–192).
[4] Wu, G., *et al.* (2002). Journal of Biomechanics, 35(4), 543–548.

## Figures

Figure 1: Examples of target (yellow) and estimated (green) lower limb bones.