The Journal of Arthroplasty 31 (2016) 1083–1090

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Basic Science

Bilateral Symmetrical Comparison of Femoral and Tibial Anatomic Features

Donald G. Eckhoff, MS, MD [a], David J. Jacofsky, MD [b], Bryan D. Springer, MD [c], Michael Dunbar, MD, FRCSC, PhD [d], Jeffrey J. Cherian, DO [e], Randa K. Elmallah, MD [e], Michael A. Mont, MD [e,*], Kenneth A. Greene, MD [f]

[a] Department of Orthopaedics, CU School of Medicine, University of Colorado–Denver/Anschutz Medical Campus, Aurora, Colorado
[b] CORE Institute, Phoenix, Arizona
[c] OrthoCarolina Hip and Knee Center, Charlotte, North Carolina
[d] Division of Orthopaedics, Dalhousie University, Halifax, Nova Scotia, Canada
[e] Center for Joint Preservation and Replacement, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, Maryland
[f] Orthopaedic and Rheumatologic Institute, Cleveland Clinic Foundation, Cleveland, Ohio

ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form
1 November 2015
Accepted 16 November 2015
Available online 17 December 2015

Keywords:
asymmetry
alignment
femur
tibia
version
anatomic comparison

ABSTRACT

Background: Variability in morphologic features of the human lower extremity within and across populations has been reported, but limb asymmetry within individuals is often overlooked. For example, in 19 studies of version of the lower extremity in the literature, 6 document asymmetry in the population, but none of these reports document asymmetry in an individual. The aim of this study was to identify the (a)symmetry and quantify variability in the tibiae and femora of matched pairs of limbs. More specifically, using a computed tomography scan database tool, we (1) identified (a)symmetry between paired left and right legs for angulation, version, and alignment features and (2) calculated the percentage of paired limbs with >1° of (a)symmetry for each evaluated parameter.
Methods: Computerized axial tomographic scans (<1.0 mm slices) from bilateral lower limbs of 361 skeletally mature subjects without bone pathology were prospectively acquired. Bones were segmented and morphologic features were measured.
Results: Angular features are symmetric left to right, but rotational features are not, with 7° of mean asymmetry in femoral anteversion (range: 0°-23°) and 3° of asymmetry in tibial version (range: 0°-8°).
Conclusions: This study disproves the hypothesis that human limbs are absolutely symmetric, confirming instead that there is asymmetry in version between left and right paired limbs. Surgeons strive for symmetry in lower extremity reconstruction, and they often compare side to side in outcome studies, believing that normal limbs are absolutely symmetric when this is not necessarily true. These assumptions concerning lower extremity symmetry need to be reassessed.

Variability in morphologic features of the human lower extremity within and across populations has been reported, but limb asymmetry within individuals is often overlooked. For example, in 8 studies of femoral anteversion identified in the literature [1-9], 3 document asymmetry in the population [1,3,4], and in 11 studies of tibial version [2,4,7,8,10-16], 3 record asymmetry in the population [10,11,13], but none of these reports addressed the asymmetry of femoral or tibial version in an individual. Another study of 20 bilateral femora addressing size, bone density, and cross-sectional rigidity found no significant difference in the left to right as a group, but the authors noted anecdotally that "absolute left-right differences for individual patients can be substantial" [5].

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to http://dx.doi.org/10.1016/j.arth.2015.11.021.

Each author certifies that his or her institution approved or waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

This work was performed at Stryker Orthopaedics, Mahwah, New Jersey.

* Reprint requests: Michael A. Mont, MD, Center for Joint Preservation and Replacement, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, 2401 West Belvedere Avenue, Suite 102-104, Baltimore, MD, 21215.

http://dx.doi.org/10.1016/j.arth.2015.11.021
0883-5403/

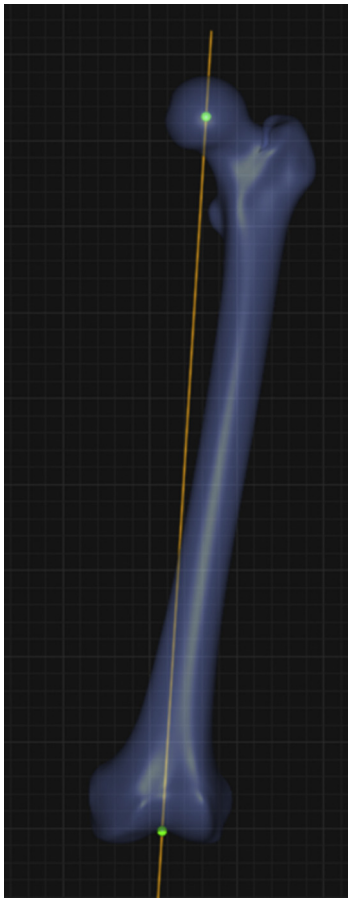

Fig. 1. Mechanical axis of the femur.

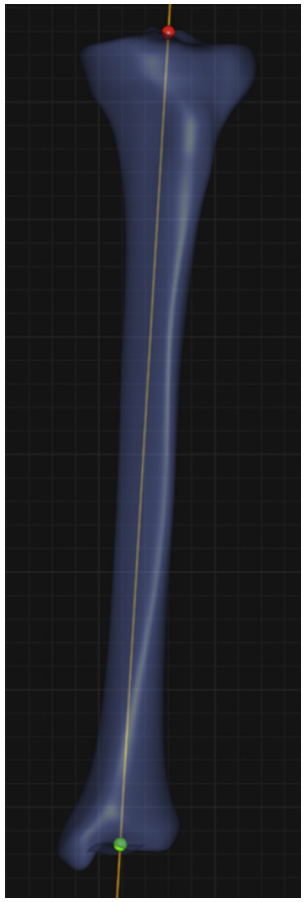

Fig. 2. Mechanical axis of the tibia.

In a radiographic study [17] and a cadaver study [18] focused on the femur, symmetry was addressed in individual right-to-left comparisons. The cadaver study concluded that there was "substantial symmetry," whereas the radiographic study concluded that "within-subject symmetry in femoral size and shape was high." It should be noted that both studies were limited to evaluation of morphologic features in 2 planes (2 dimensional), with no comment on the symmetry or lack of symmetry in 3 dimensions (3 dimensional), for example, version.

Addressing morphology specific to the knee, another study [19] found that "side-to-side comparisons of anatomical or functional parameters in the evaluation of unilateral pathologies of the human knee joint is common practice, although the amount of symmetry is unknown." In this study of 71 morphometric dimensions in 20 paired knees, asymmetry was addressed and 3 features (posterior tibial slope, anatomic valgus of the femur, insertion of the anterior cruciate ligament) were found to be asymmetric. Despite this, the authors conclude that "a good correlation in the morphometric dimensions of a human knee joint exists between the right and left."

Therefore, because of the paucity of reports in the literature analyzing individual (a)symmetry, this study was conducted to (1) identify the (a)symmetry between left and right legs by various angulation, version, and alignment features and (2) calculate the percentage of limbs with $>1^\circ$ of (a)symmetry for each evaluated parameter in matched pairs of limbs using a computed tomography (CT) scan database tool.

Materials and Methods

Skeletally mature subjects without radiographic evidence of skeletal pathology were prospectively scanned into the SOMA (Stryker Orthopaedic Modeling and Analytics) database, which is a collection of body CT scans from subjects collected globally under very strict imaging requirements and combined with a unique tool that allows for automated precise measurements such as distances, radii, or angles, on a large number of presegmented bone samples [20]. Only CT scans of the lower extremities that met the following qualifications were accepted: $\leq$1 mm voxels and slice thickness that was equal to the spacing between the slices ($\leq$1.0 mm). All cropped scans were excluded. CT scans from 361 subjects (722 knees) were included in this study. All lower extremity CT scans are derived from living patients, who were scanned for a preexisting medical condition. These scans were subsequently acquired in compliance with all ""country of origin" regulations. Therefore, they were not scanned specifically for this study, but rather we evaluated a preexisting database that has these images. All individual patient data sets are fully anonymized and archived in a secure server in Kiel, Germany, in compliance with all patient privacy protection regulations.

For each CT scan, a frontal plane was created through the 2 most posterior points of the femoral condyles and the most posterior point of the greater trochanter. These are 3 points that are the contact points of the femur if it were to lay on a flat surface. After this, a transverse plane was created perpendicular to the frontal