Automatic Landmark Propagation for Left and Right Symmetry Assessment of Tibia and Femur: A Computational Anatomy Based Approach

Christof Seiler[1], Stefan Weber[1], Walter Schmidt[2], Felix Fischer[2], Nils Reimers[2] and Mauricio Reyes[1]

[1]University of Bern,
ARTORG Center for Biomedical Engineering Research,
Stauffacherstrasse 78, CH-3014 Bern, Switzerland

[2]Stryker

February 2, 2009

Abstract

Optimal reproduction of normal femur and tibia anatomy is one of the prerequisites for successful designing implants. Usually implant design is based upon an average anatomy. However, little is known, apart from size, on the shape variability of tibia and femur anatomy in different populations. Although there is limited evidence to suggest that there are differences in symmetry between left and right, to our knowledge it has not been yet qualitatively proven. Hence, in order to highlight potential important factors of symmetry in implant design, more detailed knowledge is necessary. This work presents, based upon information from a large virtual bone database, a systematic analysis for left and right variations in femur and tibia anatomy.

1 Methods

Recent advances in quantitative computed tomography (CT) image post processing have enabled researchers to quantify variations in bone morphology between individual patients and population groups [1]. In this study, shape analysis techniques are utilized to extract femur and tibia anatomical dimensions between left and right for male and female Caucasian population groups. Equipped with this data, statistical comparisons between these groups are made to establish their statistical significance.

The proposed methodology was applied to a dataset of 72/71 male and 94/91 female left/right femur CT bone scans from patients ranging ages from 21 to 93 years old. For tibia bones the datasets consists of 68/66 male and 88/87 female, with age ranging from 17 to 90 years old. All patient were Caucasians.

Image segmentation was performed in a semi-automatic fashion in order to extract the outer shell of the femur and tibia bones. After image segmentation, reference images are selected for femur and tibia and a combined affine and non-rigid image registration [2] approach is employed to establish corresponding anatomical points across the images. Given a point x in the reference image we aim at finding the corresponding point x' such as $x' = A^{-1}(\phi^{-1}(x))$, where A and ϕ are respectively the affine and non-rigid transformations needed to morph every image into the reference one. The affine transformation allows us to deal with coarse deformations, whereas the non-rigid transformation captures the local shape variations. Landmarks are selected interactively through a Graphical User Interface on which the reference bone is displayed in a 3-D space. Consequently, distances can be propagated automatically across all the images. In addition, the landmark selection process was extended to generate cutting planes on which new landmarks are defined. The following different anatomical landmark dimensions were extracted from femur bones:

1. Bone length
2. Inter-condyles distance
3. Caput collum diaphysis angle
4. Antetorsion angle

and tibia bones:

1. Bone length
2. Plateau width
3. Plateau height
4. Plateau slope

These measurements are extracted automatically and stored for statistical analyses.

2 Results

To test the similarity between left and right datasets we chose the unpaired t-test, thus we assume a normal distribution and a similar variance. We perform unpaired tests, since the amount of bones for each side is not the same. We reject the null hypothesis when the p-values are below 0.05. The statistics for femurs, Tab. 1, shows asymmetry in all measurements except the bone length. For tibias, Tab. 2, plateau height and slope are asymmetric.

Table 1: P-values of t-tests for 8 comparisons of left and right femurs for different subgroups.

Femur landmark	Male Caucasian	Female Caucasian
Bone length	0.26	0.44
Antetorsion angle	< 0.05	< 0.05
Caput collum diaphysis angle	< 0.05	< 0.05
Inter-condyle distance	< 0.05	< 0.05

Table 2: P-values of t-tests for 8 comparisons of left and right tibias for different subgroups.

Tibia landmark	Male Caucasian	Female Caucasian
Bone length	0.07	0.07
Plateau height	< 0.05	< 0.05
Plateau slope	< 0.05	< 0.05
Plateau width	0.46	0.80

3 Discussion

A significant difference in left and right femur and tibia dimensions was found in male and female Caucasian groups. The results showed that the symmetry is independent of the gender; in all statistical test we obtained the same results for female and male bones. The length shows in both bones a significant symmetry. Interestingly, all plateau landmarks are symmetric but the width.

The automatic propagation of anatomical landmark dimensions provides us with a powerful tool able to analyze large datasets in a fast and accurate way, avoiding with this error prone manual measurements.

In the future it will be interesting to look at symmetry differences between ethnic groups.

References

[1] N. Kozic, M. Reyes, M. Tannast, L. P. Nolte, and M. A. G. Gonzalez. Assessment of Anatomical Criteria Across Populations Using Statistical Shape Models and Level Sets. In *CAOS 2008*, pages 46–49, 2008.

[2] Tom Vercauteren, Xavier Pennec, Aymeric Perchant, and Nicholas Ayache. Non-parametric Diffeomorphic Image Registration with the Demons Algorithm. In *Medical Image Computing and Computer-Assisted Intervention MICCAI 2007*, pages 319–326, 2007.