

Automatic bone density evaluation from CT images

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Introduction

The evaluation of the bone density from 2D and 3D medical images is an important task both in clinical and research fields. Clinically it is considered one of the parameters of prediction of osteoporosis and therefore bone fracture risk¹. It is commonly measured using the Dual Energy Xray Absorptiometry (DEXA), based on X-ray images of vertebrae or proximal femur and it allows the classification of the patient as normal, affected by osteopenia, or by osteoporosis. In biomedical research, the density of the bone represents an important parameter for example in those studies in which the exact knowledge of the mechanical properties of the bone are involved, such as the creation of subject-specific finite elements models² or on evaluating bone-implant fitting assessment³.

The density changes inside the bone with relationship to the region of interest. From the histological point of view, the long bones such as femur and tibia can be considered composed by three main parts⁴. The outer layer is made by cortical bone, the middle layer is composed by trabecular bone and the inner layer is represented by the marrow. The bone density decreases passing from the outer to the inner part of the bone.

In this paper we propose a method to evaluate automatically the bone density from CT images. The method was used in order to analyze possible differences between male and female bone density and the variations between the left and the right sides of the body.

Material

The dataset used in this study was composed by CT images of left and right femur and tibias of Caucasian males and females. Mean age of the patients and number of images for each group are summarized in the following tables. The images of the dataset were manually segmented previously.

FEMUR	left male	right male	left female	right female
Age [yy]	65.9±14.3	65.8±14.4	64.7±16.4	63.8±16.5
# patients	69	66	86	81

TIBIA	left male	right male	left female	right female
Age [yy]	65.9±15.4	66.4±14.7	64.1±16.6	64.7±16.4
# patients	65	61	80	78

Method

For each group of bones (femur left, femur right, tibia left and tibia right) a reference image was randomly chosen. On each reference image three volumes were manually segmented according to the histological classification: cortical bone, trabecular bone and marrow. For every bone of the dataset the voxels corresponding to the ones in the three labeled areas of the reference one were selected and their gray values extracted. The correspondences were established using the image registration technique. Two registrations were performed for each bone group. First, the rigid registration was performed to align all the bones to the same coordinate system. Second, the non-rigid registration allowed the calculation of the anatomical correspondences between voxels. It was implemented using the Diffeomorphic Demons algorithm⁵.

For each bone, each histological region was quantified using both mean and median of all the grey level values extracted. The mean was chosen in order to take into account the general pattern distribution inside each region, while the median was chosen in order to minimize the contribution of the outliers in terms of gray value.

Finally, differences between groups (male and females and right and left) were tested in order to evaluate the variations in bone density.

The whole image pipeline was implemented in C++, using ITK and VTK libraries, while the statistical evaluation was performed in R.

Results

Preliminary results showed that mean and median values are lower than expected for the cortical bone, while they were in the expected range for both trabecular bone and marrow.

Comparing male and female, preliminary results underlined higher density values for male than for female ($p < 0.05$) for the three histological regions. Moreover, it was observed that the female densities were more spread than the males' ones.

Finally comparing left and right sides, for both male and female, no significant differences were found.

Discussion

The results showed lower Hounsfield values than those expected for the cortical bone, while they were in the expected range for the other two bone regions. This could be linked to errors in the correspondence detection, due to the small thickness of the cortical bone.

The comparison between males and females underlined first higher densities for men and second larger differences among women. Both results could be linked to the variation of bone density that affects women after 40 years old.

Conclusions

An automatic technique for bone density evaluation was presented. The bone density was evaluated for femur and tibia for their three different histological regions (cortical bone, trabecular bone and marrow) analyzing the difference between male and female and left and right sides.

Keywords: bone density, image registration, biomechanical properties

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