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### Abstract

*This paper presents a standard solid model for human tibia, accounting for the material characteristics of cortical bone, cancellous bone and bone marrow. A CT scan of a cadaveric human tibia was used as the basis of developed model. A total of 201 CT scan slices of the tibia were taken with the distances between the scans varying along the length of the bone with a higher density at the proximal and distal ends, as those were the regions of interest. The data was imported into MIMICS (Materialise), and the threshold method was used to differentiate between the cortical bone region, cancellous bone region, and the bone marrow cavity. The solid model used to generate the FE model is constructed based on CT scan data of an actual cadaveric human tibia. The geometric information is retrieved and edited in (MIMICS). The surfaces defining the cortical bone, the proximal and distal epiphyseal cancellous bone and medullar cavity regions are converted into NURBS surfaces using (GEOMAGIC STUDIO).*

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# 3d Solid Modeling and Pre-Static Finite Element Modeling of Intact Human Tibia

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## Abstract

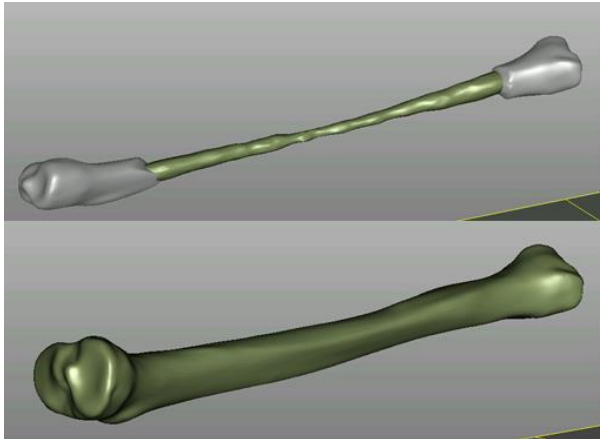
*This paper presents a standard solid model for human tibia, accounting for the material characteristics of cortical bone, cancellous bone and bone marrow. A CT scan of a cadaveric human tibia was used as the basis of developed model. A total of 201 CT scan slices of the tibia were taken with the distances between the scans varying along the length of the bone with a higher density at the proximal and distal ends, as those were the regions of interest. The data was imported into MIMICS (Materialise), and the threshold method was used to differentiate between the cortical bone region, cancellous bone region, and the bone marrow cavity. The solid model used to generate the FE model is constructed based on CT scan data of an actual cadaveric human tibia. The geometric information is retrieved and edited in (MIMICS). The surfaces defining the cortical bone, the proximal and distal epiphyseal cancellous bone and medullar cavity regions are converted into NURBS surfaces using (GEOMAGIC STUDIO).*

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## Introduction

Currently many finite element (FE) models of human bones and joints exist. Computer Tomography (CT) Scans or Magnetic Resonance Imaging (MRI) constitute the input data for a variety of software that will produce a model of the object. A finite element model (FEM) is superimposed on the geometrical one, material properties are assigned, and loading conditions are prescribed. The required analysis is then performed. Depending on the level of sophistication of the software used and the requirements of the specific research, the geometry and the FE mesh are more or less detailed and accurate.

Most FE analyses performed up to the present date for the human tibia consider the bone as an isotropic homogeneous medium. A reasonable approximation of bone is to consider it an orthotropic linear elastic solid governed by Hooke's law. Knets [1] measured the material properties of the human tibial cortical bone. Ashman et al. [2] and Rho et al. [3] correlated the orthotropic elastic moduli of the tibial cancellous bone to the bone density. Ford and Keaveny [4] determined the regression equations to be used for the longitudinal and transverse shear moduli. No study of the correlation of Poisson's ratio to the density was found in the literature.



In 2001, Cattaneo et al. [5] created an orthotropic FE model of the glenoid part of a scapula based on the data retrieved from CT and Belluci et al. [6] constructed an orthotropic but homogeneous FE model of a human femur, in which the cancellous bone is partitioned into three regions of different material properties. In 2002, Hull et al. [7] developed a very complex FE model of the human knee joint in which the cortical bone of both femur and tibia is assigned orthotropic properties but the cancellous bone is considered isotropic.

In this paper In modeling we used the same static loading conditions, which occurs during normal gait, but with different sets of material properties assigned to the tibial cancellous bone

**Figure 1. NURBS surfaces: (the epiphyseal cancellous bone and the bone marrow cavity; and the outer cortical surface.**

and FE meshes the differences in results are registered and constitute the object of an ongoing work.

Four surfaces were created corresponding to the outer cortical shell, the internal bone marrow cavity and two surfaces delimiting the epiphyseal cancellous bone. The very thin layer of cancellous bone along the diaphysis has been neglected. Figure 1 presents the NURBS surfaces created.

Finally, all data have been exported as STEP files into SDRC – IDEAS (Version 8) software

### Analysis

Three orthotropic FE models of the whole tibia have been created and constitute the object of an ongoing research. The effect of the fibula was neglected. Table 1 contains the sets of material properties assigned to the cortical and cancellous bone partitions. As bone marrow is mostly fat and does not have a support function the material properties assigned to it are the properties of air.

Material Property (MPa)	Cortical bone	Cancellous bone		
		1	2	3
$E_1$	6.91	4.48	$-98+1.52\rho$	$0.06\rho^{1.51}$
$E_2$	8.51	4.48	$-124+1.81\rho$	$0.06\rho^{1.55}$
$E_3$	18.4	9.64	$-326+5.54\rho$	$0.51\rho^{1.37}$
$G_{12}$	2.41	1.41	$931\rho$	$931\rho$
$G_{13}$	3.56	1.28	$775\rho -158$	$775\rho -158$
$G_{23}$	4.91	1.28	$775\rho -158$	$775\rho -158$
$\nu_{12}$	0.49	0.35	0.35	0.35
$\nu_{13}$	0.12	0.12	0.12	0.12
$\nu_{23}$	0.14	0.12	0.12	0.12

**Table 1. Material properties of the human tibia**

The cortical bone layer was considered homogeneous for all the models, as the properties vary only slightly through thickness. Three sets of properties for the cancellous bone layer were considered. The numerical material properties included in Table 1 are averaged.

## Modeling

A CT scan of a cadaveric human tibia was used as the basis of this present research. A total of 201 CT scan slices of the tibia were taken; the distances between the scans varying along the length of the bone with a higher density at the proximal and distal ends, as those were the regions of interest.

The data was imported into MIMICS (Materialise), and the threshold method was used to differentiate between the cortical bone

region, cancellous bone region and the bone marrow cavity. The individual elements of a CT image are called voxels and each has a

Value referred to in Hounsfield units based on the density of the structure (the value for water is 0). The threshold used in the present work for cortical bone was: 1990 – 3127 (upper limit of the scanned data), and for cancellous bone: 1100 – 1990 (both coarse and fine trabecular bone, as the trabeculae of tibial cancellous bone are almost longitudinal). The epiphyseal line was considered as part of the cancellous bone since the Hounsfield values associated did not pass

the cortical bone threshold, most probably due to the age of the specimen. The values lower than 1100 were used to construct the bone marrow cavity. Each slice was manually edited: the external and internal contours were smoothed out and internal cortical bone cavities removed. The density numbers throughout the cortical and cancellous regions were recorded in separate files to be used in determining the numerical values of the elastic and shear moduli based on the correlation equations determined in [3,4].

The geometry data for the cortical and cancellous bone regions were imported individually into GeoMagic Studio (Raindrop

Geomagic, Inc.) as point clouds. GeoMagic Studio was used to process the data in order to create Non-uniform Rational B-Splines (NURBS) surfaces, which are easily handled by FE software. After editing the data (de-noising, smoothing, filling of gaps), the curves or points were wrapped as closed manifold surfaces. A manifold surface is a trianglebased surface in which all the triangles are continuously connected by their edges, the closed kind bounds volumes. Between the values taken from the literature [1,2,5,6]. The regression equations used belong to Rho et al. [3] and Ford and Keaveny [4]. The numerical values of the density are retrieved from the CT numbers of

the actual tibia used in this research, as mentioned in the previous section. The static loading conditions were considered to be the ones occurring during normal gait at the stance phase in near full extension. The loading value of 2450 N was taken from Harrington [8]. This compressive force was distributed over the nodes at the top of the tibial plateau, with the highest loads in the approximate centers of medial and lateral areas. The total loaded area represented a fraction of 20% of the total tibial plateau area, with the medial loaded area larger

than the lateral loaded area, to reproduce a real loading situation. The degrees of freedom of the nodes in the distal epiphysis were totally constrained.

## References

- [1] Knets, I., Malmeisters, A., Deformability and strength of human compact bone tissue, Euromech Colloquium, Mechanics of Biological Solids: 133, 1977.
- [2] Ashman, R.B., Rho, J.Y., Turner, C.H., Anatomical variation of orthotropic elastic moduli of the proximal human tibia, J. Biomechanics, vol.22, no. 8/9, pp. 895-900, 1989.
- [3] Rho, J.Y., Hobatho, M.C., Ashman, R.B., Relations of mechanical properties to density and CT numbers in human bone, Med. Eng. Phys., vol. 17, no. 5, pp. 347- 355, 1995.
- [4] Ford, C.M., Keaveny, T.M., The dependence of shear failure properties of trabecular bone on apparent density and trabecular orientation, J. Biomechanics, vol. 29, no.10, pp.1309-1317, 1996.
- [5] Cattaneo, P.M., Dalstra, M., Frich, L.H., A 3-D Finite Element Model from CT data: a semi-automated method, Proc. Instn.Mech. Engrs, vol. 215, Part H, IMechE, pp. 203- 213, 2001.
- [6] Belluci, M., Di Palma, L., Apicella, A., FEM simulation of a human femur considering the bone orthotropic properties, 33<sup>rd</sup> Intl. SAMPE Tech. Conf., Nov. 5-8, pp. 648- 662, 2001.
- [7] Haut Donahue, T.L., Hull, M.L., Rashid, M.R., Jacobs, C.R., A Finite Element Model of the Human Knee Joint for the Study of Tibio-Femoral Contact, J. of. Biomech. Eng., vol.124, pp. 273-280, June 2002.
- [8] Harrington, I.J., A Bioengineering Analysis of Force Actions at the Knee in Normal and athological Gait, J. of Biomech. Eng., vol.11, pp. 167- 172, 1976.