International Journal of Computational Intelligence Systems (2024) 17:102
https://doi.org/10.1007/s44196-024-00486-9

RESEARCH ARTICLE

An Approach to Microscopic Cortical Bone Fracture Simulation: Enhancing Clinical Replication

F.D. Pérez-Cano[1] · G. Parra-Cabrera[1] · J. J. Jiménez-Delgado[1]

Received: 1 March 2024 / Accepted: 25 March 2024

Abstract
The acquisition of bone models to perform simulations is a complex and expensive process. The hierarchical structure of bones is very complex, so that studies are mainly focused on the larger scales of bones. The objective of this work is to perform a fracture simulation at the microscale level. For this purpose, the first part of the process focuses on segmenting a bone model and selecting an area of it to generate a representation of the microstructures that make up the bone tissue from a microscopic point of view. The second part is dedicated to carry out a fracture simulation in the microscopic bone model. The developed algorithm follows a statistical approach and solves the main problems of the traditional approach (FEM) to perform a bone fracture simulation. The method returns the path that a fracture follows and demonstrates how bone structures affect fracture growth. The parameters used are configurable and can be adapted for specific cases. In addition, users can reproduce as many clinical cases as desired within seconds without have to manually segment images obtained from a microscope. The data obtained may be exported to obtain synthetic images that could be used to generate datasets for machine learning tasks or other purposes.

Keywords Fracture · Microscale · Bone tissue · Simulation

1 Introduction

Computer graphics applied to medicine is a field of research with many open lines and continues to rise due to the advancement of new technologies. These advances have allowed, in the field of traumatology and bone fractures, the creation of computer assisted techniques that allow the reduction of intervention time and minimise the risk of error of specialists through the study of fractures.

The study of bone fractures is a challenging field due to the complexity of the hierarchical structure of bones. It is not possible to monitor a fracture in real time. Moreover, the issue of obtaining bone models for simulations means that most work focuses on bone at macroscopic level without taking into consideration the smaller scale levels. However, several studies of bone structures from a microscopic point of view suggest that they have a direct impact on all the phenomena that occur in bone [1–5].

The aim of this work is to propose a statistical approach for fracturing bone models from a microscopic point of view starting from a model at macroscale. The previous literature has focused on the study of the cross section and the use of 2D sketches to represent cortical tissue without longitudinal axis information. Therefore, to validate the results, our simulations have also been performed on the cross section of the bones using a 2D representation of the cortical bone. For this purpose, the process initiates with a 3D bone model and the selection of an area of the bone. In this selected area, a representation of the cortical region is generated to facilitate the simulation of the fracture. This step allows us to reproduce the clinical conditions of different patients. The approach for fracturing followed is similar to the one taken by other authors on the propagation of light on biological tissue proposed by Kumar et al. [6].

G. Parra-Cabrera and J.J. Jim'enez-Delgado have contributed equally to this work.

✉ F.D. Pérez-Cano
fdperez@ujaen.es

G. Parra-Cabrera
gparras@ujaen.es

J. J. Jiménez-Delgado
juanjo@ujaen.es

[1] Department of Computer Science, University of Jaén, Campus Las Lagunillas s/n, 23071 Jaén, Jaén, Spain

Published online: 24 April 2024

M., et al.: 3d slicer as an image computing platform for the quantitative imaging network. Magn. Reson. Imaging **30**(9), 1323–1341 (2012). https://doi.org/10.1016/j.mri.2012.05.001
32. Rosset, A., Spadola, L., Ratib, O.: Osirix: an open-source software for navigating in multidimensional dicom images. J. Digit. Imaging **17**(3), 205–216 (2004). https://doi.org/10.1007/s10278-004-1014-6
33. Mandolini, M., Brunzini, A., Facco, G., Mazzoli, A., Forcellese, A., Gigante, A.: Comparison of three 3d segmentation software tools for hip surgical planning. Sensors **22**(14), 5242 (2022). https://doi.org/10.3390/s22145242
34. Braden, B.: The surveyor's area formula. Coll. Math. J. **17**(4), 326–337 (1986). https://doi.org/10.1080/07468342.1986.11972974
35. Prendergast, P.J., Huiskes, R.: Microdamage and osteocyte-lacuna strain in bone: a microstructural finite element analysis. J. Biomech. Eng. **118**(2), 240 (1996). https://doi.org/10.1115/1.2795966
36. Doblaré, M., García, J.M., Gómez, M.J.: Modelling bone tissue fracture and healing: a review. Eng. Fract. Mech. **71**(13–14), 1809–1840 (2004). https://doi.org/10.1016/j.engfracmech.2003.08.003
37. Pfeiffer, S., Crowder, C., Harrington, L., Brown, M.: Secondary osteon and haversian canal dimensions as behavioral indicators. Am. J. Phys. Anthropol. **131**(4), 460–468 (2006). https://doi.org/10.1002/ajpa.20454
38. Britz, H.M., Thomas, C.D.L., Clement, J.G., Cooper, D.M.L.: The relation of femoral osteon geometry to age, sex, height and weight. Bone **45**(1), 77–83 (2009). https://doi.org/10.1016/j.bone.2009.03.654
39. Johannesdottir, F., Bouxsein, M.L.: Bone structure and biomechanics. In: Encyclopedia of Endocrine Diseases, pp. 19–30. Elsevier, (2018). https://doi.org/10.1016/b978-0-12-801238-3.03760-0
40. You, T., Kim, Y.-R., Park, T.: Two-way coupled multiscale model for predicting mechanical behavior of bone subjected to viscoelastic deformation and fracture damage. J. Eng. Mater. Technol. (2017). https://doi.org/10.1115/1.4035618
41. O'Brien, F.J., Taylor, D., Lee, T.C.: The effect of bone microstructure on the initiation and growth of microcracks. J. Orthop. Res. **23**(2), 475–480 (2005). https://doi.org/10.1016/j.orthres.2004.08.005
42. Yeni, Y.N., Norman, T.L.: Fracture toughness of human femoral neck: effect of microstructure, composition, and age. Bone **26**(5), 499–504 (2000). https://doi.org/10.1016/s8756-3282(00)00258-1