Perspectives in Science (2016) 8, 696—698

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# A review on application of finite element modelling in bone biomechanics☆

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Received 8 February 2016; received in revised form 12 April 2016; accepted 9 June 2016
Available online 4 July 2016

**KEYWORDS**
Finite element modelling;
Bone biomechanics;
Fracture load prediction;
Fracture fixation design

**Summary** In the past few decades the finite element modelling has been developed as an effective tool for modelling and simulation of the biomedical engineering system. Finite element modelling (FEM) is a computational technique which can be used to solve the biomedical engineering problems based on the theories of continuum mechanics. This paper presents the state of art review on finite element modelling application in the four areas of bone biomechanics, i.e., analysis of stress and strain, determination of mechanical properties, fracture fixation design (implants), and fracture load prediction. The aim of this review is to provide a comprehensive detail about the development in the area of application of FEM in bone biomechanics during the last decades. It will help the researchers and the clinicians alike for the better treatment of patients and future development of new fixation designs.


## Introduction

The finite element method was first used in bone biomechanics for analysis of mechanical behaviour of skeletal parts in 1972 (Huiskes and Chao, 1983). Steadily this method has become very popular in biomechanics field. Finite element modelling (FEM) has three major stages to analyse the human bones i.e. pre-processor, solution, and the post process stage. In the pre-process stage a CAD model is required to be generated. The geometry and material properties (CT Hounsfield Units) of bone can be acquired from computed tomography (CT). The geometry of fracture fixation (implant) is usually developed on CAD software like CATIA, Solid works, Pro/E etc. Once the bone model is developed the mesh generation is carried out. The material properties to each model is assigned and finally the boundary conditions are applied (Fig. 1). It is essential to apply the correct boundary conditions in FEM to get accurate results.

## Stress and strain analysis

The stress analysis of bones using finite element modelling is a key to understand bone remodelling, assessment of fracture risk and designing of fracture fixation. Basu et al. (1986) analysed the stresses in the adult human femur. The geometry of bone was obtained from the CT scan. Due to the

☆ This article belongs to the special issue on Engineering and Material Sciences.
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http://dx.doi.org/10.1016/j.pisc.2016.06.062

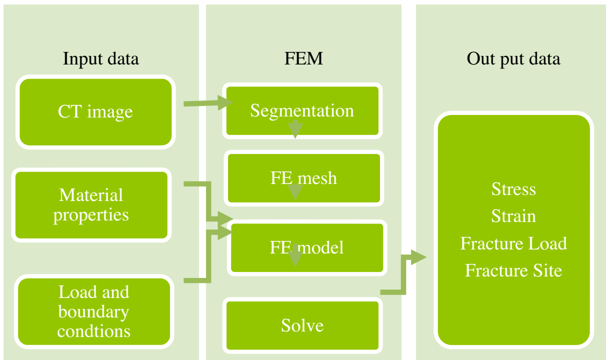


**Figure 1** Finite element modelling of bone based on CT images.

irregular stress distribution at the contact region (joint) of bones the fracture is more likely to occur at the joints in case of impact falling of human. Chand et al. (1976) determined the contact stress between the bones of human knee joints (femur and tibia) using the FEM software NASTRAN. Anderson et al. (2010) analysed the cartilage stresses in the hip joint and assumed the material of the bone to be rigid. In many papers the compact and spongy bone are modelled as isotropic and homogenous but in real conditions both type of bones have different material properties. It has been observed that the strain rate affects the human bone toughness. Ural et al. (2011) gave the effect of strain rate on cortical bone using the finite element modelling.

## Mechanical properties of bone

It is essential to predict the mechanical property (strength, stiffness, toughness, etc.) of bones in order to estimate the fracture risk. Bessho et al. (2007) predicted the strength of proximal femur and surface strain using the CT-based FEM. The FEM analysis results of bones were observed to depend on the anatomical location of specimen, because bone has heterogeneous, anisotropic material properties. In humans usually after thirty years of age, the mass of bone starts to decrease. This phenomenon is known as osteoporosis. Due to osteoporosis the mechanical properties of bones are negatively affected. Zysset et al. (2013) determined the strength of bone at the three major osteoporotic fracture site (distal radii, vertebral sections, and in side loading of proximal femora). If the estimates of the mechanical properties are accurate while modelling, the accuracy of the predicted result increases. Basafa et al. (2013) determined the stiffness and strength for femoral bone using FEM. Brown et al. (2014) estimated the mechanical properties of bone considering different volume fraction at different levels of bone. Dall'ara et al. (2012) computed strength of vertebral based on QCT- FEM. They observed that Quantitative Computed Tomography (QCT) based geometry of bone provides more accurate mechanical properties of bone than the Dual Energy X-ray Absorptiometry (DXA).

## Fracture fixation design (implant)

There are two types of fracture fixation used to fix the fracture in bone such as external skeletal fixation (POP, clamp fixators, and ring fixators) and internal fixation of fractures (plate and screw, and intramedullary nail). Simon et al. (1977) analysed the internal fixation configuration using FEM and experimental studies. The material for the plate used in their work was titanium alloy. Saidpour (2006) studied the composite plate (carbon fibre reinforced plastics) for fracture fixation and analysed the stress distribution in the composite plate. Meng et al. (2013) analysed mini-external fixation and percutaneous K-wire internal fixation. The geometry of metacarpal bone was developed on mimics while the solid model was analysed on ANSYS 10.0.

## Fracture load analysis

When the load in a particular region of a bone exceeds the ultimate strength of bone, then fracture occurs. Fracture means the continuity of bone being disrupted. Sherekar et al. (2014) analysed the human clavicle's response during collision. Munckhof and Zadpoor (2014) determined the fracture load in proximal femora using subject-specific finite element model.

## Conclusion

The finite element modelling has been developed as an effective tool in the bone biomechanics in the recent past but it has some limitation. The most important limitation in application of FEM for bone biomechanics is the lack of anatomical detail in the modelling phase, while the lack of information about the material properties of bone and bone structure also hampers its accuracy. With the recent advances in computer tomography some of these limitations have been overcome up to some extent. It is expected that with the precise determination of the mechanical properties and the structure of bones and more realistic load prediction the results from FEM can be utilised effectively for the treatment of patients and developing new fixation designs.

## References

Anderson, A.E., Ellis, B.J., Maas, S.A., Weiss, J.A., 2010. A effects of idealized joint geometry on finite element predictions of cartilage contact stresses in the hip. J. Biomech. 43, 1351—1357, http://dx.doi.org/10.1016/j.jbiomech.2010.01.010.

Basafa, E., Armiger, R.S., Kutzer, M.D., Belkoff, S.M., Mears, S.C., Armand, M., 2013. Patient-specific finite element modeling for femoral bone augmentation. Med. Eng. Phys. 35, 860—865, http://dx.doi.org/10.1016/j.medengphy.2013.01.003.

Basu, P.K., Beall, A.G., Simmons, D.J., Vannier, M., 1986. 3-D femoral stress analysis using CT scans and p-version FEM. Biomater. Med. Devices Artif. Organs 13, 163—186.

Bessho, M., Ohnishi, I., Matsuyama, J., Matsumoto, T., Imai, K., Nakamura, K., 2007. Prediction of strength and strain of the proximal femur by a CT-based finite element method. J. Biomech. 40, 1745—1753, http://dx.doi.org/10.1016/j.jbiomech.2006.08.003.

Brown, K.R., Tarsuslugil, S., Wijayathunga, V.N., Wilcox, R.K., 2014. Comparative finite-element analysis: a single computational modeling method can estimate the mechanical properties of porcine and human vertebrae. J. R. Soc. Interface 11, 1—6.

Chand, R., Huge, E., Rims, K., 1976. Stress in the human knee joints. J. Biomech., 417—422.

Dall'ara, E., Pahr, D., Varga, P., Kainberger, F., Zysset, P., 2012. QCT-based finite element models predict human vertebral strength in vitro significantly better than simulated DEXA. Osteoporos. Int. 23, 563—572, http://dx.doi.org/10.1007/s00198-011-1568-3.

Huiskes, R., Chao, E.Y.S., 1983. A survey of finite element analysis in orthopaedic biomechanics: the first decade. J. Biomech. 16, 385—409.

Meng, L., Zhang, Y., Lu, Y., 2013. Three-dimensional finite element analysis of mini-external fixation and Kirschner wire internal fixation in Bennett fracture treatment. Orthop. Traumatol. Surg. Res. 99, 21—29, http://dx.doi.org/10.1016/j.otsr.2012.07.015.

Munckhof, S.V.D., Zadpoor, A.A., 2014. How accurately can we predict the fracture load of the proximal femur using finite element models. Clin. Biomech. 1—8, http://dx.doi.org/10.1016/j.clinbiomech.2013.12.018.

Saidpour, S.H., 2006. Assessment of carbon fibre composite fracture fixation plate using finite element analysis. Ann. Biomed. Eng. 34, 1157—1163.

Sherekar, R., Ganjare, A., Pawar, A., 2014. Finite element analysis of human clavicle bone: a methodology review. Am. J. Mech. Eng. Autom. 1 (5), 54—59.

Simon, B.R., Woo, L.Y., Stanley, G.M., Olmstead, S.R., Mccarty, M.P., Jemmott, G.F., Akeson, W.H., 1977. Evaluation of one- two- and three-dimensional finite element and experimental models of internal fixation plates. J. Biomech. 10, 79—86.

Ural, A., Zioupos, P., Buchanan, D., Vashishth, D., 2011. The effect of strain rate on fracture toughness of human cortical bone: a finite element study. J. Mech. Behav. Biomed. Mater. 4, 1021—1032, http://dx.doi.org/10.1016/j.jmbbm.2011.03.011.

Zysset, P.K., Dallara, E., Varga, P., Pahr, D.H., 2013. Finite element analysis for prediction of bone strength. Bonekey Rep. 386, 1—8.