CHAPTER

16

Three-dimensional finite element modeling of human knee joint

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Abbreviations

2D two-dimensional
3D three-dimensional
BVR biplanar video-radiography
CT computed tomography
DSX dynamic stereo-radiograph
FE finite element
MRI magnetic resonance imaging
OA osteoarthritis

16.1 Introduction

Research on osteoarthritis (OA), a degenerative joint disease associated with an abnormal mechanical environment, requires full understanding in joint mechanics. Since there are no analytical solutions for knee joint contact mechanics due to geometrical and anatomical complexities, numerical methods have gained significant momentum over the past decades as a promising alternative solution. Finite element (FE) modeling of knee joints has been proven to be an efficient method in terms of determining multiple field variables such as the stress, pore fluid pressure, and interstitial fluid velocity. Understanding these parameters can bear great importance for various groups, ranging from bench-to-bedside researchers and prosthesis manufacturers to orthopedic surgeons. A brief review on the model development will be presented in this section before introducing the coverage of this chapter.

The initial FE models developed for knee joints were two-dimensional (2D). One of the first such models was used to determine the contact stress distributions of the tibia and femur bones in a sagittal plane generated from X-rays, with the aim to provide insight for prosthetic joint design [1]. The 2D FE model of a cylindrical metal implanted inside the cancellous bone was developed to assess anomalies in stress transmission accompanied by localized stiffening of the subchondral bone [2]. The tibia and femur were represented by two layers, with concave plateau and convex condyle, in order to determine the impact of joint incongruence [3]. Similarly, an axisymmetric FE model of the knee including the meniscus, femur, and tibia bones was used to determine the role of meniscus in load transmission in the knee joint, assuming all components as elastic and isotropic. The surfaces of the tibial plateau and femoral condyle were taken as flat and radially curved, respectively, and the meniscus surface was formed by occupying the empty space between the two bones [4].

It is necessary to develop three-dimensional (3D) knee models since the knee joint is highly complex and nonsymmetrical. The first 3D models of the knee joint were elastic and acquired from computed tomography (CT) [5–7] or magnetic resonance imaging (MRI) [8–10]. These studies were mainly concerned with the

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