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Modeling of human knee joint and finite element analysis of landing impact motion

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Abstract. objective:Three dimensional digital modeling of human knee joint is carried out, and the mechanical behavior of knee joint in landing impact motion is analyzed by finite element method, which provides a reasonable basis for prevention of knee joint sports injury.Methods: three dimensional geometric model of knee joint was reconstructed by software Mimics;Transforming 3D geometric model into 3D finite element model by 3-matic software;The finite element software ANSYS was used to analyze the stress and strain of the cruciate ligament, tibial cartilage and meniscus in different impact motions.Results and conclusion:1. jumping and landing impact moment, knee cartilage, ligament, meniscus stress increases with the increase of the height of jumping, the tibia, the average distribution of the lateral platform landing impact load, the stress is greater than the anterior cruciate ligament posterior cruciate ligament, jumping height is 66cm, should be the force of posterior cruciate ligament in very close to the maximum, suggesting jumping height greater than 66cm in normal life or race training is easy to damage the posterior cruciate ligament.2, the posterior cruciate ligament with limited internal rotation of the femur in knee function, under the situation that internal rotation of the femur or tibia external rotation may damage the posterior cruciate ligament.

Keywords: landing impact; knee joint; finite element analysis; modeling

1. Introduction

The finite element method has been widely used in machinery manufacturing, transportation, civil engineering and other fields as a method of mathematical physics. At present, more and more scholars tried to solve some problems in sports with this method, and obtained results. The knee joint as the largest and most complex joint plays an important role to move and maintain body posture, at same time it is the easiest to damage. In sports, such as basketball, football, badminton and other sports, athletes often urgently stop, change direction, start and brake and other compound action mode, especially the impact load of knee joint is very large at the moment of landing, so in this process, it is extremely easy to cause the knee injury. The main purpose in the paper is to establish a three-dimensional finite element model of the knee joint, including bone, cartilage, ligament, meniscus and other main mechanical bearing parts, to analysis mechanical characteristics of the knee joint with the finite element method, in order to provide bio-mechanical basis for the prevention of knee joint injury.

2. Materials and methods

2.1 The main equipment and software

Professional medical image processing software(Materialise's Interactive Medical Image Control System，Materialise Corporation，Belgium). 3-matic software, as the subsidiary software of Mimics, Geomagic Studio2014（Raindrop Corporation，U.S.A）,ANSYS/Workbench14.0（ANSYS Corporation，U.S.A）

2.2Estalishment of three-dimensional finite element model of knee joint

A male volunteer, aged 26, 170cm, 70kg, the function and structure of knee joint is normal, without history of trauma, the X examination to exclude the rheumatoid arthritis and osteoarthritis. CT scanning from

the end of the femur to foot at anatomical position, the slice thickness is 0.5mm.The scanned image is inserted into the optical disk in DICOM format.

The CT data was imported into the Mimics software, the original image was cut segmentation, for convenient operation, each mechanical component of knee was generally created a mask, and named automatically and marked in different colors. The three-dimensional model of each component of knee was established, which was composed of femur, tibia, fibula, patella, lateral collateral ligament, cruciate ligament, meniscus and cartilage after threshold segmentation, clipping mask, regional growth, morphological operations and mask editing and a series of operations, which can be enlarged, reduced, rotated, observed from any angle. The three-dimensional model of knee joint was completed through reducing the shell, smoothing and wrapping the model.

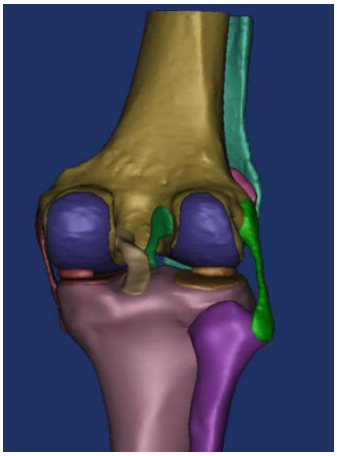

Fig1. The three-dimensional model of knee joint

There is a model's view window in the Remesh module of the 3-matic software, the quality of the triangular mesh can be examined through the window. The triangular mesh which was optimized is created as a finite element volume mesh. The element attribute of finite element is defined as solid185 element, which is defined by 10 nodes, each node has 3 degrees of freedom in XYZ direction. It has the ability of super elasticity, creep and large deformation[1], Finally, the CDB format files that can run in ANSYS are exported.

3.3 Setting of material properties of finite element model

There is a correlation between bone density and elastic modulus, although there is not a formula which can accurately calculate the relationship between bone density and elastic modulus. But under different experimental conditions, many empirical formulas have been proposed, the bone density can be calculated by the CT value of bone tissue ,so the elastic modulus can be calculated by CT value.

Fig.2 The window of evaluation

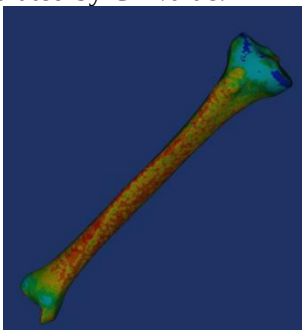

Fig.3 The model of tibia after evaluation

The material properties of biological tissue is anisotropic[2-4], the elastic modulus of bone can be obtained according to the CT value, the material properties of ligament, cartilage, meniscus came from the literature, as isotropic linear elastic materials. The material properties of ligaments are very special, which have hyperelastic properties. Many scholars[5] have studied on ligaments,In this paper, the material properties of ligaments are defined as linear elasticity.