Biomechanics Study of Knee Ligament

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Abstract

This research studies biomechanics of ligament on knee. The purpose is to calculate stress and strain distribution on knee ligament while walking. First, study anatomy of knee. Ligament is tested to obtain mechanical properties, which are used for knee behavior simulation. Next, cad model and finite element model are constructed. The stress and strain on knee's ligament while walking are calculated by finite element method. The research output is ligament behavior while walking. The maximum stress and strain occur on a top of ligament while extend leg are 33.82 MPa and 0.16 mm/mm, respectively, for 1 hamstring bundle. The maximum stress is 41.87 MPa and maximum strain is 0.18 mm/mm for 2 hamstring bundles. The advantage is to understand the biomechanics of the knee ligaments while walking. And this research result can help patients who have tear problem of an Anterior Cruciate Ligaments (ACL) and be developed for further research about force and behaviors of the other ligament and muscle in body.

Keywords: Hamstring, ACL, finite element method.

1. Introduction

The primary role of tendons or ligaments is to transmit contractile force to the skeleton to generate join movement. They do not behave as rigid bodies but nonlinear deformation behavior. Their mechanical functions are to guide normal joint motion and restrict abnormal joint movement. Their mechanical properties have been studied mostly using tensile testing methodologies, in which isolated specimens are stretched by an external force, while both the specimen deformation and applied force are record [1–3].

Ligaments can be subjected to extreme stress while performing their role in restricting abnormal joint motions and can be damaged or completely disrupted when overloaded. The four major ligaments of the knee are the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), lateral collateral ligament (LCL), and medial collateral ligament (MCL). The ACL has been acted as a primary restraint against anterior tibial displacements [4–6] and as a secondary restraint to tibial axial rotation [5, 7–9]. The ACL also provides a minor secondary restraint to varus – vargus rotation at full

extension [5]. An ACL tear is most often a sport – related injury. ACL tears can also occur during rough play, mover vehicle collisions, falls, and work-related injuries. About 80% of sports-related ACL tears are "non-contact" injuries. This means that the injury occurs without the contact of another athlete, such as a tackle in football. Most often ACL tears occur when pivoting or landing from a jump. The knee gives-out from under the athlete when the ACL is torn.

The usual surgery for an ACL tear is called an ACL reconstruction. ACL reconstruction surgery is the standard treatment for young, active people who sustain an ACL tear. A repair of the ligament is rarely a possibility, and thus the ligament is reconstructed using another tendon or ligament to substitute for the torn ligament. There are several options for how to perform ACL surgery. The most significant choice is the type of graft used to reconstruct the torn ACL. There are also variations in the procedure, such as the new single-bundle and double-bundle ACL reconstruction.

In this research the graft type of ACL reconstruction is hamstring. The ligament behavior and force are studied while patient is walking. Stress and strain of single-bundle and double-bundle ACL reconstruction are investigated by 3D finite element method.

2. Methodology

Finite element method (FEM) is used to calculate stress and strain distribution on ACL reconstruction ligament while walking. Input data of FEM are CAD model, material properties and walking load and constraint. 3D CAD models of femur and tibia are constructed from image processing of CT scan slides. Nonlinear materials are tested by tensile testing machine with freeze grips. Yeoh constitutive model is used for ligament material behavior. Dynamics motion of femur and tibia is simulated by musculoskeletal
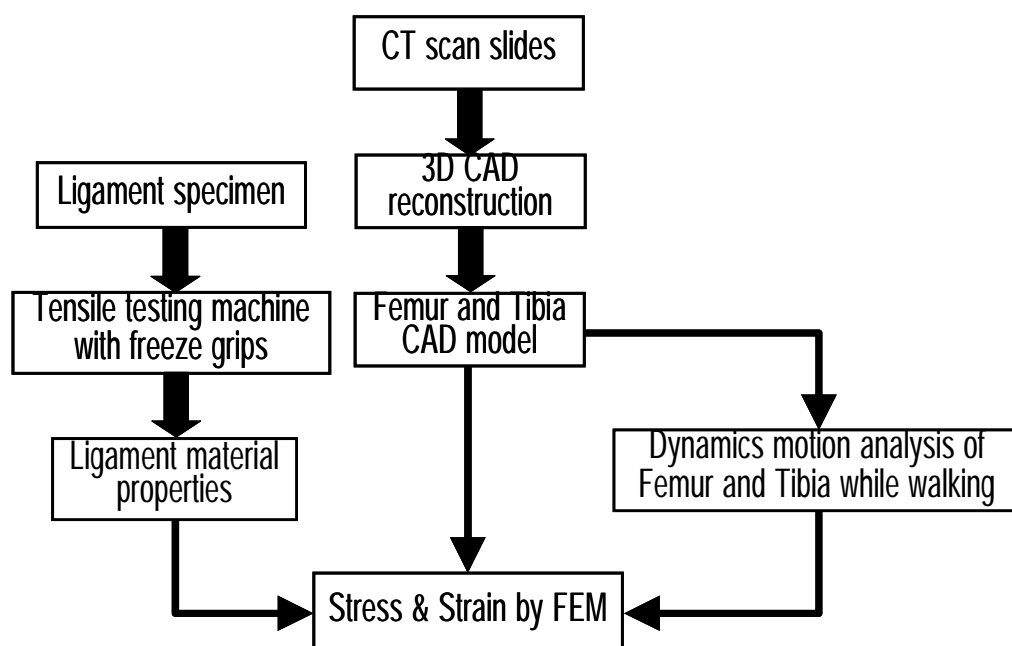

Figure 1 The proposed procedure.

system software. Results of rotational angle with respect to time while walking from musculoskeletal system software are applied as load input in finite element analysis. Hip is fixed. Two cases, single-bundle and double-bundle ACL reconstruction, are simulated. The proposed procedure used in this research as shown in figure 1.

3. Results

The results of four procedures (Ligament material properties, 3D CAD reconstructions, dynamics motion analysis, and finite element analysis) are as following.

3.1 Ligament material properties

Hamstring Ligament specimens are donated. The freeze grips clamp specimen as shown in figure 2.
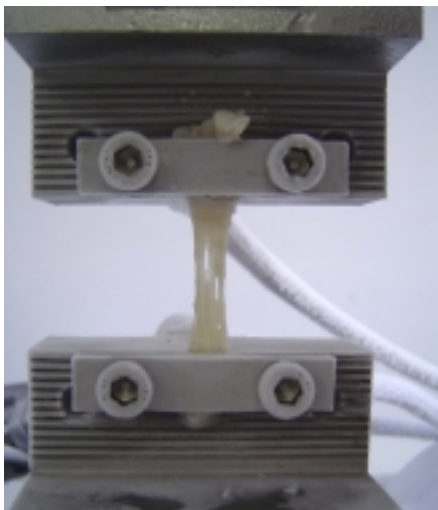
Figure 2 freeze grips clamp specimen

Average stress – strain curve of hamstring ligament is plotted in figure 3. Yeoh constitutive model is used to represent nonlinear material property. Yeoh model can fit stress – strain curve of hamstring very well.
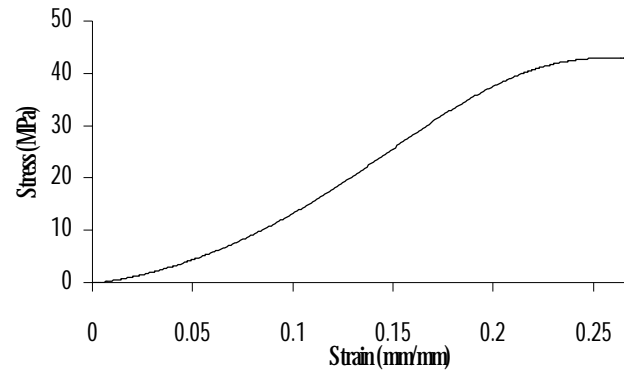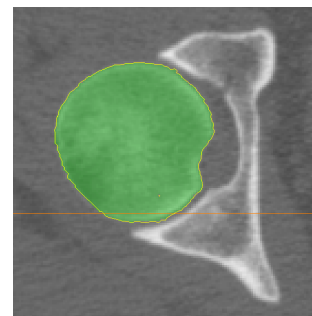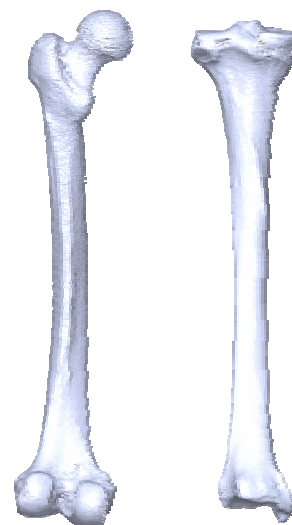

Figure 3 Stress – strain curve of hamstring

3.2 3D CAD reconstructions

The male patient is 36 years old. The CT scan is implemented to capture scan slides. These slides are under image processing process to reconstruct Femur and Tibia model as shown in figure 4.

(a) CT scan slide

(b) Femur and Tibia CAD reconstruction
Figure 4 3D CAD reconstruction from CT scan

3.3 Dynamics motion analysis

Femur and Tibia models are imported in musculoskeletal system software as shown in figure 5.
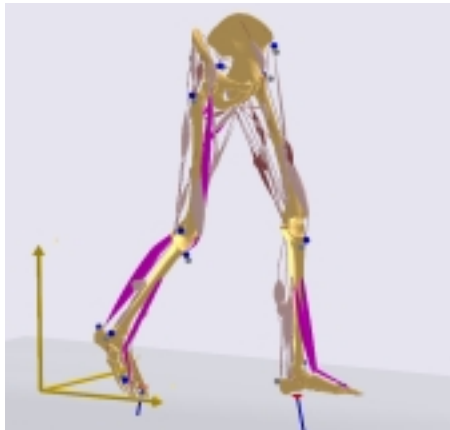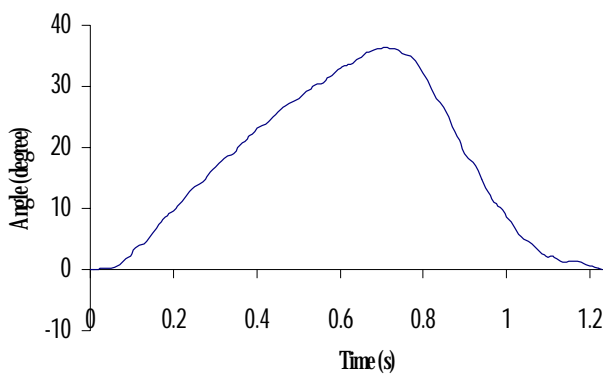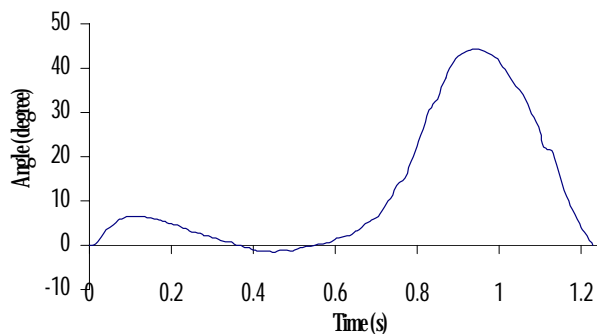

Figure 5 Modeling of Femur and Tibia

Inverse kinematics analysis is applied to calculate rotational angle and translation of hip and knee with respect to time while walking as shown in figure 6.


(a) Rotational angle of hip vs time


(b) Rotational angle of knee vs time

Figure 6 Rotational angles with respect to time

3.4 Finite element analysis

Finite element analysis is required geometry, material properties and boundary conditions to compute stress and strain solutions. Femur and Tibia models from 3D CAD reconstruction are imported. Single–bundle and double–bundle ACL reconstruction are constructed. Yeoh constitutive model of hamstring is applied. Rotational angles of hip and knee are manipulated as load. Figure 7 shows initial and final angular conditions of walking simulations.
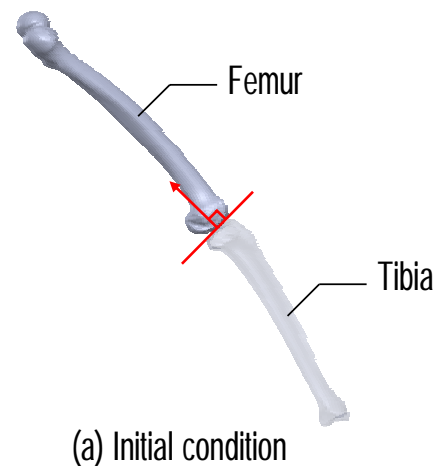
(a) Initial condition
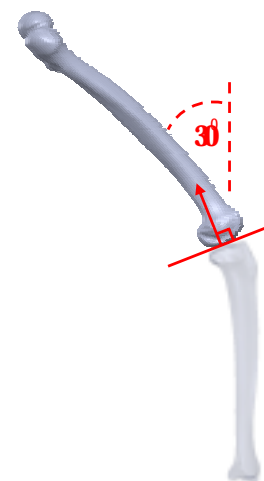
(b) Final condition

Figure 7 initial and final angular conditions of walking simulations

Finite element model of single – bundle geometry is constructed as shown in figure 8.
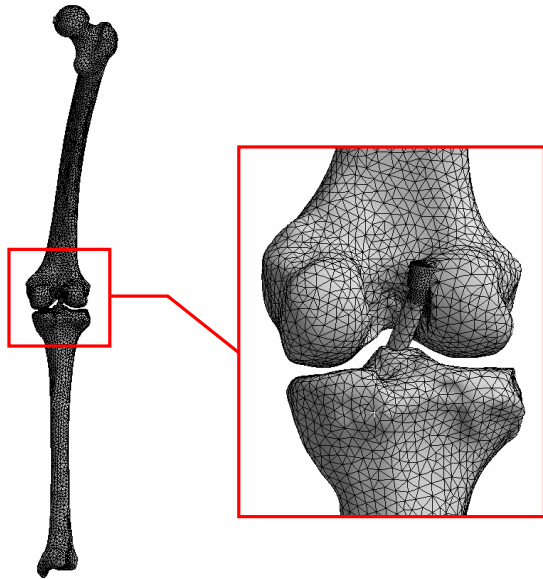

Figure 8 Finite element model of single–bundle

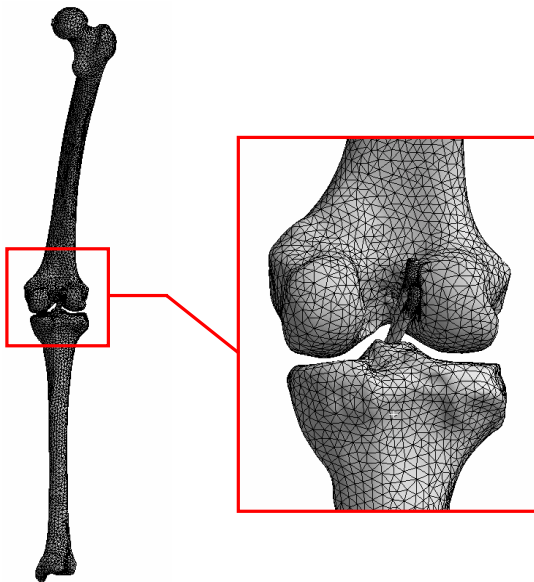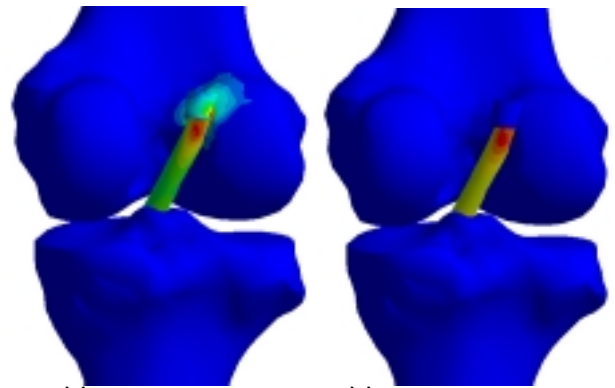Figure 9 shows FE model of double–bundle geometry.

Figure 9 Finite element model of double–bundle

Stress and strain solutions of single – bundle and double – bundle models are shown in figure 10 and 11, respectively.

(a) Stress distribution   (b) Strain distribution
Figure 10 Stress distribution of single – bundle.

The maximum stress and strain occur on a top of ligament while extend leg are 33.82 MPa and 0.16 mm/mm, respectively, for single–bundle model.
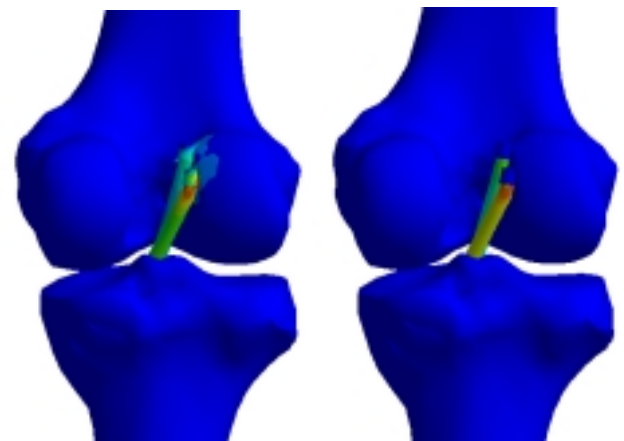
(a) Stress distribution   (b) Strain distribution
Figure 11 Stress distribution of double – bundle.

The maximum stress is 41.87 MPa and maximum strain is 0.18 mm/mm for double–bundle model.

4. Conclusions

The advantage is to understand the biomechanics of the knee ligaments while walking. And this research result can help patients who have tear problem of an Anterior

Cruciate Ligaments (ACL) and be developed for further research about force and behaviors of the other ligament and muscle in body.

5. Acknowledgement

6. References

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