FINITE ELEMENT ANALYSIS OF ACHILLES TENDON IN JUMPING PHASE

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The prevalence of Achilles tendon(AT) injury is high in various sports, but the tendon internal dynamic variation in the movement is not fully understood.Based on the CT scan and CAD/CAM software processing, the ankle three-dimensional model were created. Achilles tendon's stress-strain change were acquired through finite element analysis of one-legged jumping. The largest stress was appeared in the push phase and concentrated in the 6 cm above the calcaneal insertion. This model can be applied to research the achilles tendon, and provide mechanics data in jumping trauma.

KEY WORDS: achilles tendon; jump; non-linear analysis

INTRODUCTION:

Human Achilles tendon is subjected to substantial force during human locomotion,so it frequently associated with acute and overuse injuries related to habitual loading(Kannus,et al.,1997), including complete tendon ruptures(Maffulli,et al.,1999). It has been estimated that the human achilles tendon load may reach tensile forces of 1400-2600 N during walking(Finni,et al.,2000) and 3100-5330 N during running (Giddings et al.,2000). Due to the difficulties and lack of better techonology for the experimental measurement, the load transfer mechanism and internal stress states within the tendon and bony structures were not well addressed. The finite element analysis has been an adjunct to experimental approach to predict the load distribution at ankle (Gefen,2003;chen et al.,2001), which offer additional information such as the internal stress and strain of the whole ankle complex.

The main objective of the present study was to investigate the effect of AT biomechanics in the sports.For that purpose, we developed a three-dimensional finite element model of the healthy human ankle joint. One-legged jumping motion which made the AT suffer large force was analysised as the load condition.

METHOD:

The geometry of the finite element model was obtained from 3D reconstruction of CT (computerized tomography) images from the left foot of a normal female subject of age 21,height 168cm and weight 55kg. Coronal CT images were taken with intervals of 2mm in the neutral unloaded position. The images were segmented using MIMICS 8.0 to obtain the boundaries of the skeleton and tendon surface. The boundary surfaces of the skeletal and tendon components were processed using Solidworks2005 to form solid models and assembled into ankle part.The model was then imported in the FE package ANSYS(version 9.0).To simulate the contact between the calcaneus and AT, rigid-flexible body contact option was used(Fig.1). Compressive stiffness resembling the cartilage structure was prescribed between each pair of joint contact surface.

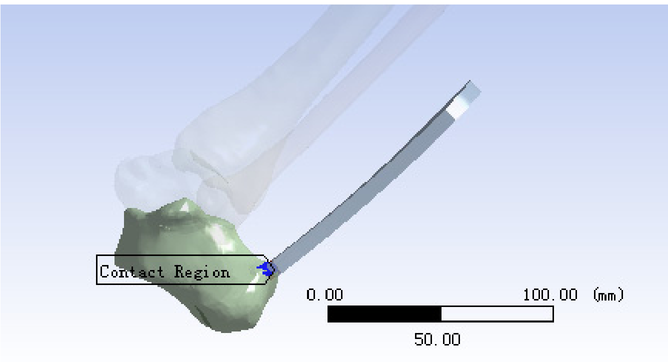


Figure 1 rigid-flexible body contact between the calcaneus and AT

The bony structures were idealized as homogeneous,isotropic and linearly elastic material. The Young's modulus and poisson's ratio for the bony structures were assigned as 7300Mpa and 0.3,according to the model developed by Zhang et al (2005). For the cartilage,Young's modulus and poisson's ratio are taken as 1Mpa and 0.4,respectively (Athanasiou et al.,1998). AT substance was simulated by using an incompressible,hyper-elastic,two parameter Mooney-Rivlin(c10,c01)formulation with the following strain energy function:

$$U = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) + \frac{1}{D}(J^{el} - 1)^2 \qquad (1)$$

where U is the strain energy per unit of reference volume;c_{10}, c_{01} are material constants, characterizing the deviatoric deformation of the material,taken as 104 and 26, respectively (Lichtwark et al.,2005). D was material incompressibility parameter,taken as 0.00484 (Weiss et al.,1996).

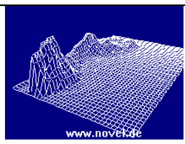
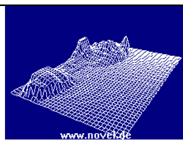
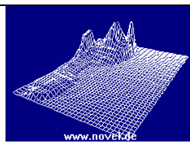
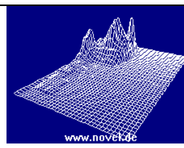
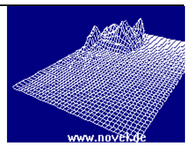
I_1 and I_2 are the first and second deviatoric strain invariants defined as:

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \qquad (2)$$

$$I_2 = \lambda_1^{-2} + \lambda_2^{-2} + \lambda_3^{-2} \qquad (3)$$

The reaction plantar force and surface EMG of triceps surae muscle generated during the foot-ground interaction and their evolution during jumping are important parameters to estimate the AT force (Finni et al.,1998). An in-shoe force measurement system(Novel Pedar system,Germany) was employed to measure the ground reaction force during the female subject jumping(Tab.1).

Table 1 Plantar pressure distribution during one-legged jumping

	Heel-strike	Midstance	Forefoot-contact	Push-Off	Toe-Off
Pressure Distribution					
P-pressure(Kpa)	555.8±70.7	295.0±19.4	417.5±26.3	605.0±33.8	330.0±15.7
Force (N)	1414.9±65.2	1560.2±20.3	1817.8±81.5	1525.3±18.2	796.1±13.6

EMG activity of the gastrocnemius and soleus(Tab.2) were collected during the jumping using the Mega(Me6000) system.

Table 2 EMG data of triceps surae muscle during one-legged jumping

	Soleus	Medial gastrocnemius	Lateral gastrocnemius
AEMG (microV)	298.43±25.66	467.00±53.65	434.75±74.30
MPF (Hz)	70.36±3.05	71.40±5.03	86.60±2.61

RESULTS:

A geometrical accurate 3D FE model of the human ankle part was developed. The model is able to predict the internal stress/strains within bones and AT under various loading conditions. Fig.2 depicts the von Mises stresses in the ankle (left) and stress line distribution(right) predicted by the FE simulation during heel strike.AT suffer little stress as the model predicted,the peak von Mises stress was 0.05Mpa appeared at calcaneal insertion.

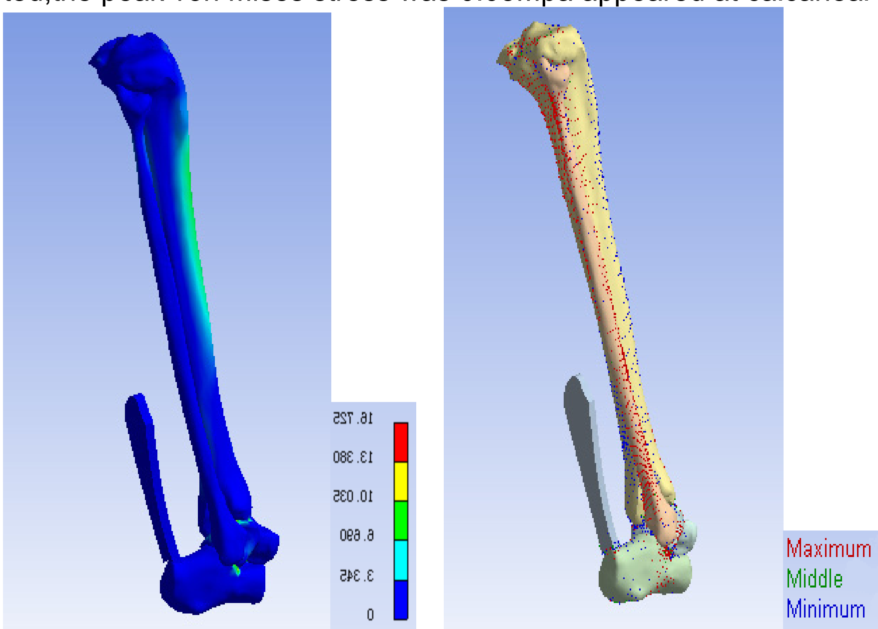


Figure 2 stress ditribution at heel strike

During midstance, the AT became to receive tension and the peak von Mises stress/strain were 22.66Mpa/4.15%.The AT's max von Mises stress/strain was found at push-off (Fig.4), which is 48.37Mpa/5.14%.Simulation of the AT during toe-off subphase also revealed high stress/strain (26.57Mpa/4.33%). Fig.3 shows the AT stress variation in the jumping as the simulation predicted.

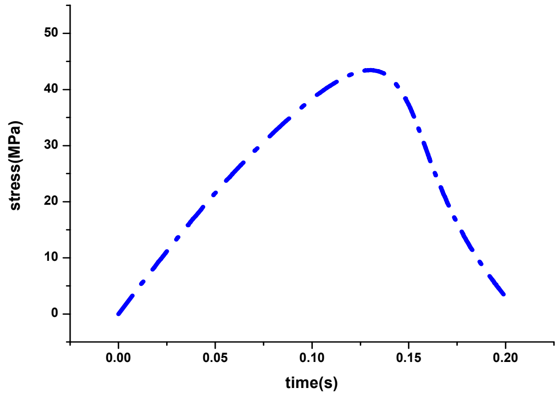


Figure 3 Achilles tendon stress variation during the one-legged jumping

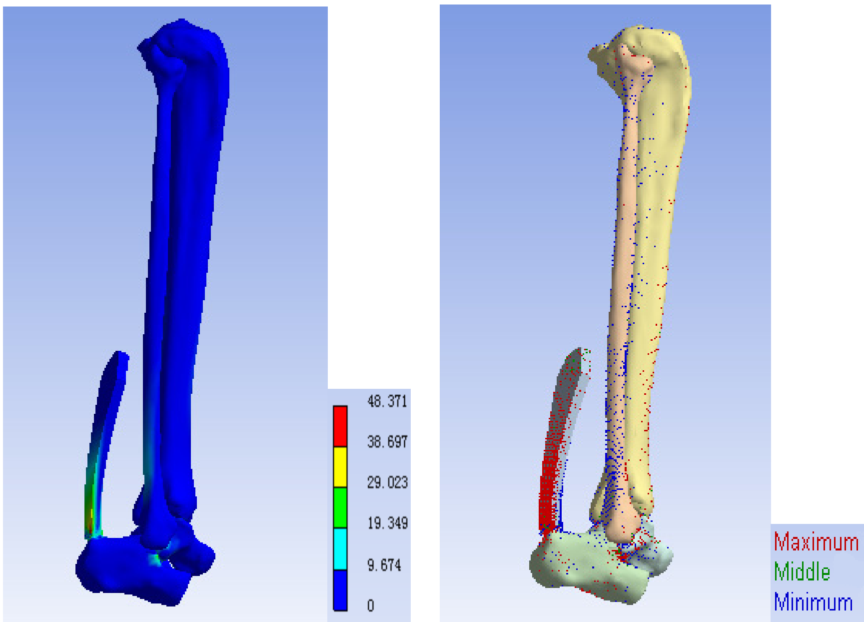


Figure 4 stress ditribution at push-off

DISCUSSION:

In this study, a 3D FE model of the ankle part was developed using the actual geometries of the bony and tendon. Approximately 80% of Achilles tendon ruptures occur 3 cm to 6 cm above the calcaneal insertion (Aroen et al.,2004). The specific site of rupture has traditionally been explained by a poor blood supply (Maffulli et al.,2003).However, it has been suggested that focal stress concentration as the model simulation also the main reason lead to AT injury. Tendon ruptures always related to overuse,because of the fatigue parameter of AT material, this work will be the future development.

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