Effect of femoral tunnel angle on tunnel enlargement in anterior cruciate ligament reconstructions

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Abstract — ***Introduction*** **The aims of this study were to explore whether the angle of the femoral tunnel had effect on the contact pressure of the graft in the femoral tunnel and to find the best femoral tunnel with the aim of minimizing bone tunnel enlargement after anterior cruciate ligament (ACL) reconstruction.**

Materials and methods **A three-dimensional (3D) finite element (FE) model of a healthy human knee which comprised proximal tibia, distal femur, ligaments, menisci and articular cartilages was developed. Besides, five FE models of femoral tunnels which were 10°, 20°, 25°, 30° and 40° relative to the midcoronal plane respectively and each FE model of tibial tunnel and Ligament Advanced Reinforcement System (LARS) were constructed. A load of 40N was applied to the quadriceps and each load of 10N was applied to the biceps femoris and semitendinosus tendons of the FE model. The contact pressures of the simulated graft in the femoral tunnel wall were measured at 0°, 30°, 60°, 90° and 120° of knee flexion.**

Results **The contact pressure at anterior portion of 40° femoral tunnel was significantly higher than those of 10°, 20°, 25° and 30° femoral tunnels. The contact pressure at posterior portion of 10° femoral tunnel was significantly higher than those of the other four tunnels. The contact pressure at posterior portion of 20° femoral tunnel was higher than that of 25° femoral tunnels. The contact pressure at anterior portion of 30° femoral tunnel was significantly higher than that of 25° femoral tunnel.**

Conclusion **The results obtained showed that the femoral tunnel angle had noticeable effect on the contact pressure in the femoral tunnel which could lead to femoral tunnel enlargement and the 25° femoral tunnel was the best femoral tunnel minimizing the femoral tunnel enlargement after ACL reconstruction.**

Keywords — **Finite element method, Anterior cruciate ligament reconstruction, Bone tunnel enlargement, Knee biomechanics, Tunnel angle**

I. Introduction

Bone tunnel enlargement is a common phenomenon after ACL reconstruction[1, 2]. The vast majority of previous studies showed that bone tunnel enlargement did not have effect on clinical outcome[1]. However, bone tunnel enlargement often complicates revision ACL reconstruction[3] and increases its cost. A proper understanding of the etiology of bone tunnel enlargement is therefore essential to prevent its occurrence. Despite that many studies have been performed to find out the exact causes of bone tunnel enlargement, the causes are not completely known yet. Biological and mechanical factors have been reported as potential causes of this phenomenon[4]. The mechanical factors consist of stress deprivation of bone within the tunnel wall, graft-tunnel motion, an accelerated rehabilitation, as well as improper tunnel placement[5]. Segawa et al.[2, 6] concluded that the contact pressure in the femoral tunnel was influenced by the angle of the femoral tunnel. However, Kobayashi[1] reviewed retrospectively thirty ACL reconstructions performed with hamstring tendons, and believed that the femoral tunnel angle had no clear effect on the prevalence of bone enlargement. Here we presented a complete 3D FE model of a healthy human knee joint to the effect of femoral tunnel angle on tunnel enlargement in anterior cruciate ligament reconstructions.

II. Materials and methods

The geometrical data of the knee model was acquired from a healthy young volunteer by nuclear magnetic resonance (MRI) scan. The contours of bones, articular cartilages, ligaments and menisci were identified by automatic contouring software (Mimics10.0), and used to construct the solid models with the help of Geomagic, a reverse engineering software. The IGES files of solid models were transferred into the ANSYS software of FE analysis to mesh the solid models.

Models of bone tunnels whose diameters were 7.5 mm were created through Boolean operation. Tibial tunnel was centered at the location described by the literature[7], and with an angle of 30°relative to the midsagittal plane and 65°relative to the tibial plateau from the lateral view[7, 8]. The isometric point of femoral tunnel located 6mm anterior to the over-the-top point. The femoral tunnels were created 30° relative to the midsagittal plane, and 10°, 20°, 25°, 30° and 40° relative to midcoronal plane respectively (Fig. 2).

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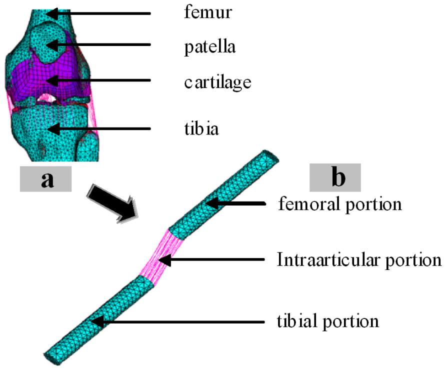

Fig. 1 finite element models: (a) knee joint; (b) LARS artificial ligament

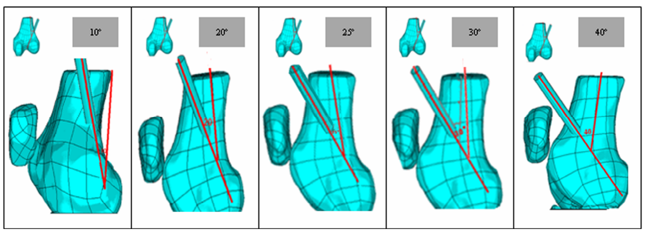

Fig. 2 solid models of femoral tunnel: 30° relative to the midsagittal plane, 10°, 20°, 25°, 30° and 40° relative to the midcoronal plane respectively.

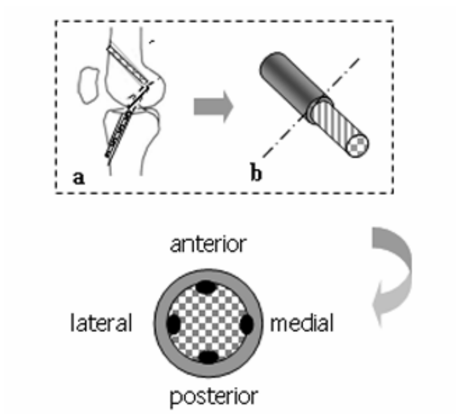

Fig. 3 schematic diagram of the contact pressure of the graft in the femoral tunnel. The grids represent the graft, the grey ring represents the femoral tunnel wall and the four black points represent the direction of contact pressure. (a) schematic diagram of LARS ligament in the tunnels (b) schematic diagram of femoral tunnel and intraarticular portion of LARS ligament.

The models of intraarticular and extraarticular portions of LARS ligament formed a nunchaku-type FE model (Fig.1 b).

A load of 40N was applied to the quadriceps and each load of 10N was applied to the biceps femoris and semitendinosus tendons. The contact pressures of the simulated grafts in the walls of the femoral tunnel models which were 10°, 20°, 25°, 30° and 40° relative to midcoronal plane respectively were measured at 0°, 30°, 60°, 90° and 120° of knee flexion(Fig. 3).

III. Results

The graphs in Fig4. showed the values and dynamic changes of contact pressures of the grafts in each portion of the 5 femoral tunnels. The values and dynamic changes of contact pressures at the anterior and posterior portions of the femoral tunnel were evident throughout the knee flexion, while those of the contact pressures at the medial and lateral portions of the femoral tunnels were minimal. Peak contact pressures appeared in the anterior portion of the 40° femoral tunnel at 0° of flexion and in the posterior portion of 10° femoral tunnel at 120° of flexion. When the knee was in full extension, the contact pressure was the highest at the anterior portion and the lowest at the posterior portion. As flexion progressed, the contact pressure at anterior portion gradually decreased but increased at posterior portion.

The contact pressures of graft in the femoral tunnel varied with the femoral tunnel angle. The contact pressure at anterior portion of 40° femoral tunnel was significantly higher than those of 10°, 20°, 25° and 30° femoral tunnels. The contact pressure at posterior portion of 10° femoral tunnel was significantly higher than those of the other four tunnels. Differences of the contact pressure at anterior portion between 20° and 25° femoral tunnel were not evident. But the contact pressure at posterior portion of 20° femoral tunnel was higher than that of 25° femoral tunnels. The contact pressure at anterior portion of 30° femoral tunnel was significantly higher than that of 25° femoral tunnels, while that at posterior portion of the two tunnels were almost the same.

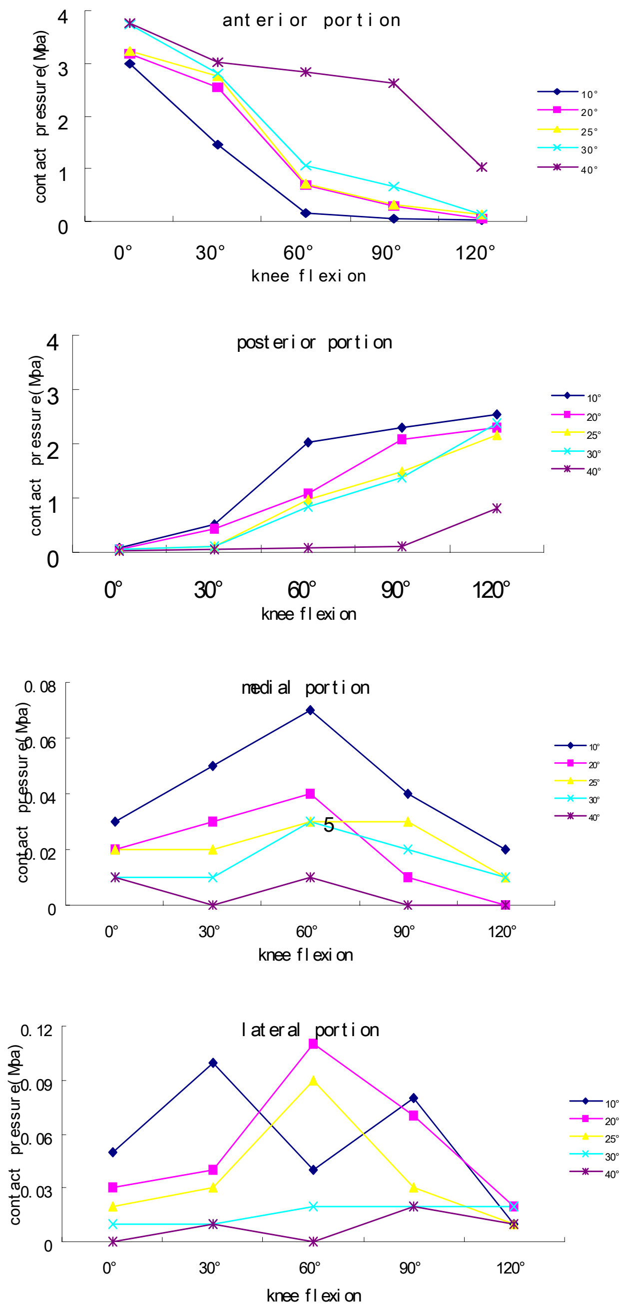

Fig. 4 The contact pressures of the LARS ligament at the walls of the five femoral tunnels at different knee flexion angle.

IV. Discussion

Stress deprivation of bone within the tunnel wall is one of the most important mechanical factors that contribute to bone tunnel enlargement. A graft in a malposition tunnel might be shifted to the physiological position, leads to the occurrence of the contact pressure of the graft in the tunnel wall and finally results in bone tunnel enlargement[9]. We here presented a FE model to analyze the effect of the femoral tunnel angle on the contact pressure of the graft in the bone tunnel wall, and to find a femoral tunnel with a certain angle minimizing bone tunnel enlargement after ACL reconstruction. The finite element method is a useful tool for biomechanical research which can overcome the inherent limitations of cadaveric experiment such as the difficulties of accurate measures of stresses and strains and sometimes impossible reproduction of the natural or pathological situations.

As shown in Fig.4, the contact stress at anterior portion of 40°femoral tunnel was significantly higher than that of the10°, 20°, 25°, and 30° femoral tunnels. As the angle of the femoral tunnel decreased from 40° to 10°, the contact pressures in the anterior portion decreased too. Therefore, the anterior portion of the 40° femoral tunnel was more likely to be widened because of the stress deprivation of the femoral tunnel bone. For the same reason, bone tunnel enlargement occurred at the posterior portion of 10° femoral tunnel more likely than the other four. The contact pressure at posterior portion of 20° femoral tunnel was higher than that of 25° femoral tunnels. The contact pressure at anterior portion of 30° femoral tunnel was significantly higher than that of 25° femoral tunnels at 0°, 60° and 90° of knee flexion, while that at posterior portion between the two tunnels were almost the same. Based on these analysis, we conclude that among the five different femoral tunnels, the contact pressures of the graft in 25° femoral tunnel was the most minimal. Thus considering only from the mechanical view, the 25° femoral tunnel was the best femoral tunnel with the aim of minimizing the bone tunnel enlargement.

The obtained results were close to the result from the experimental, demonstrating that this FE models can effectively simulate the influence of the femoral tunnel angle on the contact pressure of the graft in the femoral tunnels. We conclude that the femoral tunnel angle has much effect on the contact pressure of the graft in the femoral tunnels which could lead to femoral tunnel enlargement, and that from the mechanical view, the 25° femoral tunnel is the best femoral tunnel which could minimize the femoral tunnel enlargement.

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