ARTICLE IN PRESS
THEKNE-02535; No of Pages 10
The Knee xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
The Knee

Influence of knee flexion angle and transverse drill angle on creation of femoral tunnels in double-bundle anterior cruciate ligament reconstruction using the transportal technique: Three-dimensional computed tomography simulation analysis

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ARTICLE INFO

Article history:
Received 2 May 2017
Received in revised form 19 July 2017
Accepted 11 September 2017
Available online xxxx

Keywords:
Arthroscopy
Anterior cruciate ligament
Reconstruction
Double bundle
3D simulation

ABSTRACT

Background: The purpose of this study was to find appropriate flexion angle and transverse drill angle for optimal femoral tunnels of anteromedial (AM) bundle and posterolateral (PL) bundle in double-bundle ACL reconstruction using transportal technique.
Methods: Thirty three-dimensional knee models were reconstructed. Knee flexion angles were altered from 100° to 130° at intervals of 10°. Maximum transverse drill angle (MTA), MTA minus 10° and 20° were set up. Twelve different tunnels were determined by four flexion angles and three transverse drill angles for each bundle. Tunnel length, wall breakage, inter-tunnel communication and graft-bending angle were assessed.
Results: Mean tunnel length of AM bundle was >30 mm at 120° and 130° of flexion in all transverse drill angles. Mean tunnel length of PL bundle was >30 mm during every condition. There were ≥1 cases of wall breakage except at 120° and 130° of flexion with MTA for AM bundle. There was no case of wall breakage for PL bundle. Considering inter-tunnel gap of >2 mm without communication and obtuse graft-bending angle, 120° of flexion and MTA could be recommended as optimal condition for femoral tunnels of AM and PL bundles.
Conclusion: Flexion angle and transverse drill angle had combined effect on femoral tunnel in double-bundle ACL reconstruction using transportal technique. Achieving flexion angle of 120° and transverse drill angle close to the medial femoral condyle could be recommended as optimal condition for femoral tunnels of AM and PL bundles to avoid insufficient tunnel length, wall breakage, inter-tunnel communication and acute graft-bending angle.

1. Introduction

Anterior cruciate ligament (ACL) insufficiency leads to an alteration of kinematics and functional impairment of the knee [1]. Over the past few decades, there have been various considerations on the surgical treatment method for ACL insufficiency to restore normal knee kinematics and improve functional outcomes. In the early 2000s, several studies showed that only about 30–40% of patients treated with ACL reconstruction were reported as normal while the majority of patients had recurrent

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https://doi.org/10.1016/j.knee.2017.09.005
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instability or an inability to recover function prior to injury [2]. Additionally, long-term studies revealed drawbacks with arthritic change and poor functional outcomes after ACL reconstruction due to limitation in restoration of normal knee kinematics [3]. To redeem such defects, the double-bundle concept was considered as one of the alternatives on the basis of native ACL anatomy. The double-bundle anatomy of the ACL was identified decades ago [4]. However, it began to receive attention in clinical practice in the 2000s [5,6]. Biomechanical studies supported double-bundle ACL reconstruction by establishing differing kinematic roles of each bundle [7,8] and noted that double-bundle ACL reconstruction led to improvement of outcomes by restoring knee kinematics close to the normal ACL [9]. Although controversy exists over clinical outcomes, double-bundle ACL reconstruction has been considered to have more antero-posterior and rotational stability compared to single-bundle reconstruction according to previous studies [10].

In performing ACL reconstruction, the location of the femoral tunnel is considered as a key factor in yielding successful outcomes [11]. Efforts to place the femoral tunnel in the anatomical position of native ACL were devoted and anatomical ACL reconstruction using outside–in technique and transportal technique was suggested [12,13]. There have been reports of pros and cons regarding both techniques. Outside–in technique has the shortcoming of needing another lateral femoral dissection using an additional incision. In contrast, transportal technique does not need an additional incision, but has drawbacks such as insufficient tunnel length and posterior wall blow-out [12,14]. In this regard, previous studies regarding single-bundle ACL reconstruction noted that flexion angle of knee [15,16] and transverse drill angle [15] affected the characteristics of femoral tunnel and suggested that flexion angle should be increased and the far anteromedial portal be made at a lower position [14] to achieve a sufficient length of tunnel without wall breakage. An additional point to consider is the graft-bending angle. Graft-bending angle increases with increased knee flexion angle. It results in higher tunnel acuity and contact pressure [17]. To the best of our knowledge, there has been no previous study dealing with the characteristics of femoral tunnel including tunnel length, posterior wall breakage and graft bending angle which change according to the combined effect of various flexion angles of knee and transverse drill angles during double-bundle ACL reconstruction. Creation of femoral tunnel in double-bundle ACL reconstruction using transportal technique is performed based on studies regarding single-bundle ACL reconstruction [15,16]. Additionally, one of the most important elements of the double-bundle ACL reconstruction is to create two tunnels while preserving an intact bone bridge between tunnels with no inter-tunnel communication. Communication between two tunnels jeopardizes function of reconstructed graft and stability of knee, and leads to difficulty in revision surgery [18,19]. The purpose of the present study is to find appropriate conditions of knee flexion angle and transverse drill angle for optimal femoral tunnels of each bundle which include sufficient tunnel length without wall breakage, obtuse graft-bending angle and no communication between two tunnels in double-bundle ACL reconstruction using transportal technique. The present study was performed using three-dimensional (3D) computed tomography (CT) simulation.

2. Materials and methods

2.1. 3D reconstruction of computed tomography scans

Knee CT images of subjects who took a CT scan to evaluate the trauma of the knee from January 2011 to December 2012 were retrospectively reviewed after approval by the institutional review board of our institution. The CT evaluation was performed with the CT scanner Sensation 64 (Siemens healthcare, Erlangen, Germany). The tube parameters were 120 kVp and 135–253 mAs. The acquisition matrix was 512 × 512 pixels. The scan field of view was 134–271 mm, and the slice thickness was 0.6 to one millimeter. A CT scan was performed with the knee in full extension. Subjects were included in the current study according to the following criteria: (1) no ligament injury of knee; (2) no osseous deformity including fracture of femur and tibia; (3) no previous operation history; and (4) no osteoarthritis above Kellgren–Lawrence grade I [20]. CT images of 30 subjects were included in the present study. Digital Imaging and Communications in Medicine (DICOM) data were extracted from the picture archiving and communication system (Centricity PACS, GE Medical System Information Technologies, Milwaukee, Wisconsin). Extracted CT images were imported into Mimics software (version 17; Materialise, Leuven, Belgium) and a 3D model of the femur and tibia was reconstructed.

2.2. Simulation of femoral tunnel drilling on a 3D-reconstructed model

To establish footprint centers of anteromedial (AM) and posterolateral (PL) bundles of ACL on femur, the 3D-reconstructed model of the femur was aligned in a true lateral position where both femoral condyles were superimposed, as noted by Bernard et al. [21], and the medial femoral condyle was virtually removed from the 3D-reconstructed model at the most anterior aspect of the intercondylar notch to improve visualization of the medial wall of the lateral femoral condyle [22]. Footprint centers of each bundle were determined according to the previous study dealing with 3D CT using a cadaver [23]. Similar to the quadrant method for standard lateral radiograph a 4 × 4 grid was drawn on the medial wall of the lateral femoral condyle from a true medial view of the femur established at 90° of knee flexion. Because there was no Blumensaat line on a 3D-reconstructed model, the most anterior edge of the femoral notch roof was regarded as the reference for the grid alignment. The femoral footprint center of each bundle was located according to reference point coordinates determined by the segments of the grid along the Blumensaat line and the segments of the grid perpendicular to the Blumensaat line. The point which was located at 21.7% of the distance measured from the posterior border of the medial wall of the lateral condyle along the line parallel to the Blumensaat line and at 33.2% of the distance measured from the Blumensaat line along the line perpendicular to the Blumensaat line was set for the center of femoral footprint of AM bundle. The point which was located at 35.1% of the distance measured from the posterior border of the medial wall of the lateral condyle along the line parallel to the Blumensaat line and at 55.3% of the distance measured from the Blumensaat line along the line

Please cite this article as: Choi CH, et al, Influence of knee flexion angle and transverse drill angle on creation of femoral tunnels in double-bundle anterior cruciate ligam..., Knee (2017), https://doi.org/10.1016/j.knee.2017.09.005