Roentgenographic measurement study for locating femoral insertion site of anterior cruciate ligament: a cadaveric study with X-Caliper

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Abstract The purpose of this study was to determine the relationships of the anterior cruciate ligament (ACL) femoral insertion site with femoral bony landmarks and develop a new method of location. Sixteen unpaired normal Chinese human cadaveric knees were used. Femoral insertion sites of the ACL were marked with metal wires. Four pairs of bony landmarks were selected: anatomical axis of distal femur (A) and parallel tangent of posterior condyles (B); tangent of anterior condyles parallel to landmark A (C) and landmark B; Blumensaat's line (D) and parallel tangent of distal condyles (E); and tangent of posterior condyles (F) and parallel tangent of anterior condyles (G). The X-Caliper was used to measure the distance between the centre of the insertion site and each pair of bony landmarks. The ratio of distances to each pair of bony landmark was calculated. Clock position of the ACL femoral footprint was measured on anteroposterior (AP) roentgenograms at 90 degree flexion. The centre of the ACL footprint was found at $65.3\% \pm 1.1\%$ between A and B, $78.1\% \pm 1.0\%$ between B and C, $38.3\% \pm 2.7\%$ between D and E, and $43.1\% \pm 4.6\%$ between F and G. The distances to bony landmarks A, B, D, and E have smaller variations. Blumensaat's line and the anatomical axis of the distal femur were regarded as more useful and made location of the insertion site more precise. A parallelogram made up of these two bony landmarks can be used. On AP roentgenograms, the centre of the femoral footprint should be moved to lower than the 10:00 o'clock (2:00) position.

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Résumé Le propos de cette étude est de mettre en évidence l'insertion du ligament croisé antérieur par un marquage osseux fémoral et développer une nouvelle méthode pour localiser cette insertion. Matériel et méthode: 16 genoux de cadavres chinois non appariés ont été utilisés. Les lieux d'insertion du ligament croisé antérieur ont été repérés avec un fil métallique. 4 types de repère ont été sélectionnés: l'axe anatomique du fémur distal (A) et la tangente parallèle au condyle postérieur (B); b la tangente du condyle antérieur parallèle au repère A (C) et au repère B; c, la ligne de Blumensaat (D) et la tangente parallèle des condyles distaux (E); d, la tangente des condyles postérieurs et des condyles antérieurs (G). Un outil de mesure (X-Caliper) a également été utilisé pour mesurer les distances entre les insertions et chaque repère. La position de l'insertion fémorale du ligament croisé antérieur a été appréhendée sur les radiographies de face à 90° de flexion. Résultat: le centre de l'insertion du ligament croisé antérieur a été trouvé pour $65,3\%$ IA $1,1\%$, entre A et B $78,1\%$ IA $1,0\%$ en A1, 0% entre B et C, $38,3\%$ IA, $2,7\%$ entre D et E, $43,1\%$ IA $4,6\%$ entre F et G. Les distances entre ces différentes marques varient peu. En conclusion, la ligne de Blumensaat et l'axe anatomique du fémur distal peuvent être utilisés comme les repères les plus utiles pour localiser l'insertion du ligament croisé antérieur de façon précise. Un parallélogramme peut être réalisé à partir de ces différents repères radios. Sur la radiographie de face le centre de l'empreinte du ligament croisé antérieur peut être abaissé sur la position 10 H (2:00).

Introduction

ACL reconstruction under arthroscopy is the most widely used surgical procedure in treatment of ACL injury. Ideally,

graft should be inserted at the original attachment site of ACL to achieve anatomical reconstruction [9, 16]. Reconstruction outside anatomical femoral attachment has a high incidence of failure [6]. Methods of locating tibial attachment sites have been fully discussed in many papers [13, 18]. Location of femoral attachment remains relatively difficult and questionable because of its special anatomy in the intercondylar notch. The centre of rotation of the knee is closer to the femoral attachment than the tibial attachment. Therefore, accurate placement of the femoral tunnel is more critical than the tibial tunnel if knee kinematics are to be optimised [12, 15]. Femoral tunnel placement is believed to be an important factor in early failure ACL reconstruction [5, 11]. Harner [10], Aglietti [1], and Edwards [3] developed methods to locate the femoral tunnel centre using roentgenograms. All these methods used Blumensaat's line as the only landmark to describe attachment location, which decreased the accuracy of graft placement [23]. Consistent measurements documenting femoral graft placement in ACL reconstruction are difficult to obtain. Only the measurement techniques described by Amis produced substantially reliable data [21]. Up to now, there is no universal roentgenographic method widely accepted. ACL acts as the main restrained as well as guiding force during knee joint motion. To some extent, location of ACL insertion site is related to the anatomical and mechanical factors of femur and tibia. Bony landmarks on the lateral roentgenogram stand for anatomical and mechanical characters of femoral condyles. If proper pairs of landmarks were selected rather than only Blumensaat's line, more accuracy could be achieved during location of ACL attachment. But not every bony landmark is easily recognised and precisely profiled on lateral roentgenograms. So the accuracy of each bony landmark in locating the ACL footprint should be compared. In this study, we used Blumensaat's line, the anatomical axis of the distal femur, its parallel tangent to anterior and posterior condyles, and the tangent of posterior condyles as bony landmarks. After the relationship between bony landmarks and femoral footprint of ACL was determined, a new locating method could be created.

Methods

Sixteen unpaired normal fresh-frozen human cadaveric knees (9 male and 7 female, age 29 to 44 yrs) were used. These specimens were fresh frozen in a refrigerator at -30°C and defrosted at room temperature for 12 hours overnight before the experiment. Capsule, posterior cruciate ligament, and fat pad were removed, and femur and tibia were preserved 20 cm from the joint line. Femoral condyles were split from the middle as Klos described [21]. The femoral insertion site of ACL was discerned and marked

with metal wires (5 mm in length and 1 mm in diameter). We obtained lateral roentgenograms from each knee in full extension and made a precise overlapping of the double femoral condyles (Fig. 1). Several bony anatomical landmarks were used to identify the precise femoral insertion site of ACL (Table 1). The geometrical centre of the ACL femoral insertion site was marked on the radiograph. Four pairs of parallel bony landmarks were also marked: anatomical axis of distal femur (A) and parallel tangent of posterior condyles (B); tangent of anterior condyles parallel to landmark A (C) and landmark B; Blumensaat's line (D) and parallel tangent of distal condyles (E); tangent of posterior condyles (F) and parallel tangent of distal condyles to F (G) (Fig. 2). The distances from attachment site centre to each pair of landmarks were measured with the X-Caliper (CGTech, USA). The position of the geometrical centre of the insertion site was recorded as the ratio between each pair of landmarks. Anteroposterior (AP) roentgenogram was taken at 90 degree of knee flexion. The clock method was used to describe position of ACL femoral footprint border. The superior edge of the clock was located as high as the level of the superior arc of intercondylar notch. The inferior edge of the clock reached the tangent of hind condyles (Fig. 3). On AP films, the centre, superior, and inferior borders of the attachment site were also marked and their clock positions were measured on intercondylar notch clock (Fig. 4). The angle mode of X-Caliper was used to measure the clock position of each part of the footprint. Each

Fig. 1 Bony landmarks on lateral roentgenogram. **a** Anatomical axis of distal femur (A) and parallel tangent of posterior condyles (B). **b** Tangent of anterior condyles parallel to landmark A (C) and landmark B. **c** Blumensaat's line (D) and parallel tangent of distal condyles (E). **d** Tangent of posterior condyles (F) and parallel tangent of distal condyles to F (G)

Table 1 Bony landmarks on lateral femoral X-ray

Bony landmarks	Distance to centre of ACL footprint
A Anatomical axis of distal femur	A
B Parallel tangent of posterior condyles to A	B
C Parallel tangent of anterior condyles to A	C
D Blumensaat's line	D
E Parallel tangent of distal condyles to D	E
F Tangent of posterior condyles	F
G Parallel tangent of distal condyles to F	G

measurement was repeated five times by five different observers. Arithmetic mean value, standard deviation, and coefficient of variation were calculated. Value of coefficient of variation was regarded as the accuracy of the certain pair of landmarks in locating the attachment site.

Results

The centre of the ACL femoral footprint was found at the 13:7 ratio point ($65.3\% \pm 1.1\%$) between landmark A and B, at the 11:3 ratio point ($78.1\% \pm 3.8\%$) between B and C, at the 2:3 ratio point ($38.3\% \pm 1.3\%$) between D and E, and at the 2:3 ratio point ($43.1\% \pm 4.6\%$) between F and G. The standard deviations of percentage ratio between landmarks 'A and B' and 'D and E' were smaller than that of the other two pairs of bony landmarks. Values of coefficient of variation between A and B (0.017) and D and E (0.034) were also smaller than that of the other two pairs (0.049 and

Fig. 2 Diagram of bony landmarks on lateral roentgenogram **Fig. 3** Clock position of femoral attachment of ACL on AP roentgenogram

0.107, respectively) (Table 2). Landmarks A, B, D, and E were used to make up a parallelogram for locating the geometric centre of the ACL femoral footprint. The centre lies at the 13:7 ratio point between A and B and at the 11:3 ratio point between B and C. Clock positions of different parts of the ACL femoral footprint were listed (Table 3).

Discussion

Arthroscopically-assisted ACL reconstruction is one of the most popular and advanced techniques developed in recent

Fig. 4 Different part of ACL femoral footprint on AP roentgenogram. F1: superior border of footprint. F2: middle point between F1 and F3. F3: centre of footprint. F4: middle point between F3 and F5. F5: inferior border of footprint

Table 2 Percentage ratio of ACL footprint between pairs of bony landmarks

Bony landmarks ACL footprint	A and B a/(a+b)	B and C c/(b+c)	D and E d/(d+e)	F and G g/(f+g)
Anterior	48.8 ± 1.70%	67.6 ± 1.40%	—	—
Posterior	82.3 ± 0.60%	88.9 ± 0.50%	—	—
Superior	—	—	—	16.4 ± 2.70%
Inferior	—	—	—	73.3 ± 6.73%
Centre	65.3 ± 1.10%	78.1 ± 1.00%	38.3 ± 2.70%	43.1 ± 4.60%

— represents immeasurable values

years. Accurate tunnel placement is expected to help resolve inconsistencies in reconstructing techniques. Therefore, the method of locating attachment site during operation is important. Fluoroscopically-assisted locating methods have been reported to increase the accuracy of graft placement [1, 3, 8, 10, 21, 23], and they are especially helpful to locate the femoral tunnel [17]. Of the most frequently used methods, Amis' method has been proven to be more accurate and repeatable than Harners and Aglieffi's [21]. But only one landmark had been used to locate the centre of attachment. Then, a quadrant method was reported using the greatest diameter of femoral condyles as a reference based on anatomical studies by Bernard et al. [2]. Although this has been shown to be more accurate because two bony landmarks were used, mechanical factors of ACL attachment related to femur were still not considered. Acting as a complicated restrained as well as guiding force during knee joint motion, substitution of the ACL should be inserted into the original site that was related to the mechanical axis of the femur. Using the anatomical axis of the femur as a reference to locate the ACL insertion site takes the mechanical characters of the knee into consideration, and the use of more than one bony landmark led to an accurate location of the attachment site. Different parts of the femoral insertion site can be seen as a percentage ratio point between each pair of landmarks. Once these percentage ratios were calculated, a marker line could be drawn between and parallel to each pair of landmarks and cross the exact percentage ratio point where the attachment is located. Different parts of the femoral

footprint can be located precisely by crossing two marker lines between different pairs of landmarks. In this study, we only calculated the relationship of centre of femoral footprint to the parallelogram. To make a good parallelogram, at least two sets of landmarks are needed. The anatomical axis of the distal femur (A) and the parallel tangent of the posterior condyles (B) were regarded as accurate references which concern mechanical characteristics of the distal femur. In addition, it is not easy to be influenced by minor rotation of the femur when roentgenograms were taken. Blumensaat's line (D) [4] and its parallel line (E) were accurate in locating and are also very clear and easily recognised on lateral film. Selection of the landmarks that form the parallelogram was based on the accuracy and invariance when drawing the landmarks locating the centre of the ACL femoral footprint. Drawing of landmark C is based on a parallel line to A. This may decrease the accuracy during the course of making a tangent line of anterior femoral condyles parallel to A. The shape of the femoral trochlea could also influence the measurement result. To make the landmarks of F and G accurate depends on recognising of the curve of posterior condyles. The quality of the overlapping of posterior condyles on roentgenograms can significantly influence the accuracy of location of the ACL femoral footprint regarding the statistical result.

Table 3 Clock position of different parts of ACL femoral attachment site ($\bar{x} \pm SD$)

Parts of femoral footprint	Clock position
F1 (superior edge)	10.4 ± 1.25
F2	10.1 ± 1.05
F3 (centre)	9.7 ± 0.62
F4	9.2 ± 0.35
F5 (inferior edge)	8.1 ± 0.40

Fig. 5 Parallelogram method locating the centre of the ACL femoral footprint. Landmarks A, B, D, and E were used to make up a parallelogram for locating the geometric centre of the ACL femoral footprint. The centre lies at the 13:7 ratio point between A and B and at the 11:3 ratio point between B and C

Tomoyuki described the femoral insertion site of ACL as two parts according to distribution of the anteromedial bundle (AMB) and the posterolateral bundle (PLB). The position of the AMB on the clock was 1:40 (11:20) and that of PLB was 3:10 (8:50) [22]. This has been proven by a cadaveric study of Giron [7]. There is a tendency in recent literature that the ACL reconstruction position should move to about the 10:00 (2:00) position according to intercondylar notch clock [14, 19, 20, 24]. Reconstruction of the ACL covering the anatomical attachment site of the femoral footprint as much as possible is currently an important principle and one that will effectively resist rotary loads and transmission. Thus, the centre, superior, and inferior borders of the ACL femoral footprint can be seen as an important intraoperative reference point. Lintner et al. [16] marked the ACL footprints and found the femoral attachment of the ACL occupied the upper two thirds of the notch on an intercondylar notch view on roentgenograms (anteroposterior projection at 60° of knee flexion). According to our result, when the knee joint was bent to 90° of flexion, the centre of the femoral footprint was near the 9.7 position, which confirms the concept of lowering the insertion point during ACL reconstruction. The superior border of the footprint lies at about the 10:30 (2:30) position, while the inferior border is as low as the 8:00 (4:00) position.

Conclusions

The centre of the ACL femoral footprint was found at the 13:7 ratio point between landmarks A and B and at the 2:3 ratio point between D and E (Fig. 5). The parallelogram method can be used to locate the ACL femoral footprint centre on lateral films. Then the coverage range of the footprint should be located on AP films from 10:30 to 8:00. Although this primary study has shown encouraging results for using the anatomical axis and Blumensaat's line as references to locate the femoral attachment site of ACL on lateral film, further cadaver research is still needed to validate our conclusion.

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