ORIGINAL ARTICLE

Radiographic evaluation of the tunnel position in single and double bundle anterior cruciate ligament reconstruction

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ABSTRACT

Aim To evaluate tunnel positioning on radiographs in single-bundle (SB) and double-bundle (DB) anterior cruciate ligament (ACL) reconstruction, to evaluate if measurement is accurate and reproducible.

Methods Radiographs of 30 SB and 30 DB ACL reconstruction were reviewed by two examiners who measured tunnel positioning with the quadrant method on the femur (a=depth, b=height) and the Amis and Jakob method on the tibia. Intra- and inter-observer reliability were evaluated with intra-class correlation coefficient (ICC).

Results A radiographic analysis was completed in all patients in a SB-group and in 27 in a DB-group ($p>0.05$). Intra-observer reliability was almost perfect on femoral (ICC: a=0.85, b=0.83) and tibial (ICC=0.87) side in the SB-group. In the DB-group, it was almost perfect for tibial anteromedial (AM) and posterolateral (PL) bundles (ICC: AM=0.84, PL=0.81) and for femoral PL bundle (ICC: a=0.83, b=0.82), and substantial for femoral AM bundle (ICC: a=0.78, b=0.74). Inter-observer reliability was almost perfect on tibial (ICC=0.81) and femoral (ICC: a=0.81, b=0.87) side in the SB-group, and substantial on tibial (ICC: AM=0.71, PL=0.77) and femoral (ICC: AM a=0.73, b=0.78; PL a=0.74, b=0.76) side in the DB-group. Standard deviation (SD) was low (±9%) with respect to the centre of tunnel(s).

Conclusion The quadrant method and the Amis and Jakob method are accurate and reproducible measurement methods. Also, as SD was low, an outside-in approach with a front-entry guide, which is free-hand positioned, can be postulated as a reliable method to locate the femoral tunnel in SB reconstruction and the AM bundle in DB reconstruction.

Key words: anatomic reconstruction, quadrant method, radiographic analysis, tunnel placement

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INTRODUCTION

Anatomical anterior cruciate ligament (ACL) reconstruction has been deemed necessary to obtain better clinical results (1–3). Correct positioning of tunnels is pivotal, and femoral tunnel position greatly affects tension and isometry of the graft (4,5). Different approaches to drill the femoral tunnels have been proposed: transtibial, transportal through the anteromedial (AM) or an accessory AM portal, outside-in using a rear-entry guide through a posterolateral (PL) incision or a front-entry guide through the anterolateral (AL) portal. At our Institution, an outside-in approach using a front-entry guide was finally opted for; also, a prototype guide to drill the PL bundle in double bundle (DB) reconstruction was developed and techniques and results have been previously published (3,6). While there is no clear evidence in literature that supports DB over single bundle (SB) technique with respect to post-operative results (7–9), recent literature supports the concept that clinical outcomes of ACL reconstruction surgery would be linked to correct femoral tunnel positioning (10). Native ACL femoral insertion has been described (5,11), and cadaveric biomechanical and radiographic studies on anatomical landmarks useful for femoral tunnel positioning have been published (12–17).

Radiologic data of tunnel position can be used for surgical purposes and for post-operative evaluation, and three-dimensional (3D) computed tomography (CT) analysis for determining tunnel position is deemed as the gold standard although this technique is not convenient in terms of costs and radiation exposure. Also, 3D magnetic resonance imaging (MRI) has been proven to be as accurate as CT and more accurate than plain radiographs (18,19), but it is much more expensive. Nevertheless, measurements achieved by radiograph analysis are reliable if compared with those obtained by CT-scan (20–23). Substantial evidence supports, as the most reproducible ad reliable methods to identify tunnel position on sagittal radiographs, the "quadrant method" described by Bernard and Hertel (24) for the femur and the Amis and Jakob's method (13) for the tibia.

The aim of this study was to investigate the radiographic positions of the tunnels in SB and DB reconstruction using these two radiographic methods, and to compare results with those reported in literature.

PATIENTS AND METHODS

Patients and study design

Two groups of 30 patients each who underwent an arthroscopic assisted SB or DB ACL reconstruction at Azienda Ospedaliero-Universitaria Careggi from 2015 to 2018 were retrospectively picked-up in a casual fashion from a prospectively collected database and included into the study. Informed patient consent and Ethical Committee consent were obtained at the time of previous studies; no further consent was required for this study.

Methods

ACL reconstruction was performed using an autologous hamstring graft and a double incision outside-in approach in all cases (6). In SB-group, tunnels were drilled aiming to exit in the centre of tibial and femoral ACL insertion areas. The tibial tunnel was drilled referring to anatomic landmarks described by Jackson and Gasser (12) using the 65° Howell Tibial Guide (previously Arthrotek, Ontario, CA; now ZimmerBiomet, Warsaw, IN, USA). The femoral tunnel was drilled on the lateral femoral condyle (LFC) viewing via the AM portal using a front-entry guide inserted through the AL portal (Acufex Director Drill Guide, Smith & Nephew, Andover, MA, USA). In DB-group, the AM tunnels were drilled first. On the tibia, the bullet of the 65° Howell Tibial Guide was rotated to get a more AM position, then the PL guide-wire was positioned using the prototype rod-guide inserted into the AM tunnel that allowed to exit posterior and lateral to the AM tunnel at a fixed distance of 8 mm. On the femur, the AM guide-wire was inserted near the posterior cartilage below the over-the-top position with the above-mentioned front-entry guide; the PL tunnel was drilled 9 mm apart, distal and shallow from the AM tunnel, about 5 mm from the cartilage border, using the prototype rod-guide through a different hole.

Standard anterior-posterior (AP) and true lateral radiographic views were taken at 1- and 2-year follow-up (FU) in every patient, according to our protocol (25). In order to achieve the best femoral condyles superimposition, lateral radiographs were taken with fluoroscopic image intensifier to find correct rotation. Femoral and tibial intra-articular tunnel aperture positions were measured, independently and twice with 8-week interval, by two examiners on the 2-year FU lateral views. On the femur, the centres were measured according to the quadrant method (24). The total sagittal diameter of the LFC along the Blumensaat's line (distance t) and the maximum intercondylar notch height (distance h), tangent to the most dorsal subchondral contour of the LFC and perpendicular to the distance t were measured. Then the distance from the tunnel centres to the distance h (distance a) and to the distance t (distance b) were measured and expressed as percentage of distance t (depth, being 0% deep/posterior and 100% shallow/anterior) and distance h (height, being 0% high/superior and 100% low/inferior) (Figure 1). On the tibia, the centres of tunnels were orthogonally projected onto the maximum sagittal tibial diameter and then expressed as percentage being 0% anterior and 100% posterior (Figure 2).

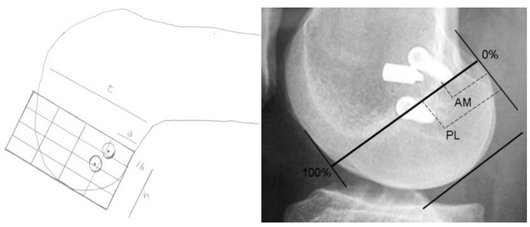

Figure 1. The quadrant method described by Bernard and Hertel (24) for femoral tunnel(s) position. Depth is expressed as 0% deep/posterior and 100% shallow/anterior. Height is expressed as 0% high/superior and 100% low/inferior. Location of intra-articular opening of the tunnel(s) was not an obstacle for superimposition of the metallic interference screws (Giannini L, 2019)
AM, anteromedial bundle; PL, posterolateral bundle; h, maximum intercondylar notch height; t, total sagittal diameter of the lateral femoral condyle along the Blumensaat's line; a, distance from the femoral tunnel centres to the distance h; b, distance from the femoral tunnel aperture to the distance t

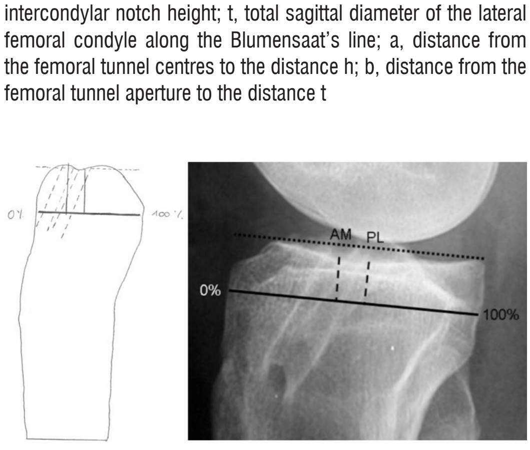

Figure 2. The method described by Amis and Jakob (13) for tibial tunnel(s) position. Length is expressed as 0% anterior and 100% posterior (Giannini L, 2019)
AM, anteromedial bundle; PL, posterolateral bundle

Statistical analysis

Reliability of measurements was evaluated by means of intra-class correlation coefficient (ICC). Test-retest reliability was determined with intra-observer ICC which measures the correlation between results obtained by the same observer on separate occasions, and with inter-observer ICC which measures the correlation between results obtained by different examiners. ICC ranged from 0 to 1. According to Landis and Koch guidelines (26), the degree of agreement was considered to be excellent (ICC greater than 0.91), almost perfect (ICC between 0.9 and 0.81), substantial (ICC between 0.61 and 0.80), moderate (ICC between 0.41 and 0.60) or fair (ICC between 0.21 and 0.40).

RESULTS

A radiographic analysis was completed in all patients in the SB group and in 27 in the DB group ($p>0.05$). None of the two examiners was able to define PL femoral aperture in one patient, AM femoral aperture in another patient and PL tibial aperture in the third patient (Table 1, 2).

Table 1. Centre of intra-articular tunnel apertures in single bundle (SB) group according to the quadrant method (24) on the femur and to the Amis and Jakob's method (13) on the tibia

Variable	**Femur** (mean±SD) (%)		**Tibia** (mean±SD) (%)
	a	**b**	
Observer 1	25±4	28±7	46±5
Observer 2	25±6	33±5	43±7
Average	25±5	30.5±6	44.5±6

a, height; b, depth on the lateral femoral condyle

Table 2. Centre of intra-articular tunnel apertures in double bundle (DB) group according to the quadrant method (24) on the femur and to the Amis and Jakob's method (13) on the tibia

Variable	**Femur** (mean±SD) (%)				**Tibia** (mean±SD) (%)	
	AM		**PL**		**AM**	**PL**
	a	**b**	**a**	**b**		
Observer 1	24±4	26±9	35±4	42±8	43±6	53±3
Observer 2	22±6	22±7	36±6	47±6	38±5	50±5
Average	23±5	24±8	35.5±5	44.5±7	40.5±4	51.5±4

AM, anteromedial bundle; PL, posterolateral bundle; a, height; b, depth on the lateral femoral condyle

Intra-observer reliability of the quadrant method was quoted almost perfect in the SB group (ICC: a=0.85, b=0.83), substantial for AM tunnel (ICC: a=0.78, b=0.74) and almost perfect for PL tunnel (ICC: a=0.83, b=0.82) in the DB group. Inter-observer reliability was almost perfect in the SB group (ICC: a=0.81, b=0.87) and substantial in the DB group for both AM (ICC: a=0.73, b=0.78) and PL tunnels (ICC: a=0.74, b=0.76).

Table 3. Comparison between results of the present study (*in vivo*) versus previous *in vitro* studies on cadaveric knees, entire anterior cruciate ligament (ACL) footprints*

Comparison	Method	Femur (mean±SD) (%) Entire ACL a	Femur (mean±SD) (%) Entire ACL b	Tibia (mean±SD) (%) Entire ACL	Notes
Present study	X-rays	25 ± 5	30.5 ± 6	44.5 ± 6	
Cadaveric knees					
Bernard and Hertel. (13)	X-rays	24.8 ± 2.2	28.5 ± 2.5	-	
Musahl et al. (27)	X-rays	27.5 ± 3.2	26.9 ± 3.5	46.2 ± 2.8	No differences between X-rays and CT-scan
	CT-scan	26.6 ± 1.9	26.3 ± 2.4	45.4 ± 2.1	
De Abreu-e-Silva et al. (28)	CT-scan	35.3 ± 4.5	30 ± 1.6	40.5 ± 5.3	
Guo et al. (29)	X-rays	38.3 ± 2.7	43.1 ± 4.6	-	Slightly different method

*The quadrant method of Bernard and Hertel (13) as in Figure 1 was used for the femoral footprint and the Amis and Jakob's methods (13) as in Figure 2 for the tibial footprint except where noted

a, height; b, depth on the lateral femoral condyle; X-rays, radiographs; CT-scan, computed tomography scan

Intra-observer reliability of the Amis and Jakob method was quoted almost perfect in the SB group (ICC=0.87) and almost perfect in the DB group (ICC: AM=0.84, PL=0.81). Inter-observer reliability was almost perfect in the SB group (ICC=0.81) and substantial in the DB group for both tunnels (ICC: AM=0.71, PL=0.77).

Standard deviation (SD) was low (±9%) with respect to the centre of tunnel(s).

DISCUSSION

The main finding of this study in our opinion is the reliability of femoral tunnel positioning with the outside-in technique using a guide which is free-hand positioned to locate the intra-articular tunnel opening, referring to visible landmarks (5,16). This technique was used to locate the femoral tunnel in the SB group and the AM femoral tunnel in the DB group. Comparison between *in vivo* results of the present study and *in vitro* results of literature are reported in Table 3 (entire ACL) and Table 4 (separate AM and PL bundle measurements).

The centre of the femoral tunnel in the SB group was located at 25±5% in deep-shallow and 30.5±6% in high-low direction, a position superimposable to those reported on cadaveric knees (24, 27–29). Bernard and Hertel found the centre of ACL femoral insertion to be located at 24.8±2.2% of depth and 28.5±2.5% of height on the LFC (24). Musahl et al. (27) and de Abreu-e-Silva et al. (28) found similar results; differences between radiographs and CT-scan evaluations were not statistically significant (27). On the other hand, Guo et al. found different data, but a slightly different method of measurement was used (29).

The AM femoral tunnel in the DB group was located at 23±5% / 24±8% of depth / height of the LFC. Again, this position was consistent with that reported in literature (14,17,21,23,30). Interestingly, Lee et al. did not find any difference in evaluated parameters between anatomic dissection, radiographs and CT-scan (23).

In this series, the femoral PL tunnel in the DB group was positioned at 35.5±5% and 44.5±7% of depth and height of the LFC, respectively. This

Table 4. Comparison between results of the present study (*in vivo*) versus previous *in vitro* studies, double bundle anterior cruciate ligament footprints*

Comparison	Method	Femur (mean±SD) (%) AM a	Femur AM b	Femur PL a	Femur PL b	Tibia (mean±SD) (%) AM	Tibia PL	Notes
Present study	X-rays	23±5	24±8	35.5±5	44.5±7	40.5±4	51.5 ± 4	
Cadaveric knees								
Colombet et al. (14)	X-rays	26.4±2.6	25.3±4.2	32.3±3.9	47.6±6.5	36	52	
Zantop et al. (17)	X-rays	18.5	22.3	29.3	53.6	30	44	Stäubli and Rauschning's technique (33)
Iriuchishima et al. (21)	X-rays	15±6	26±8	32	52	31	50	Stäubli and Rauschning's technique (33)
Pietrini et al. (30)	X-rays	21.6±5.6	14.2±7.7	28.9±4	42.3±6	36.3	51	
Lee et al. (23)	X-rays	33.5±4.7	27.6±5.4	38.3±4	55.1±7.1	36.3±5.6	43.4±5	no differences between X-rays, CT-scan and anatomic dissection
	CT-scan	34.2±4.3	26.3±5.8	38.7±4	53±5	36.7±3.8	42.2±4.2	
	Anatomic dissection	33.9 ± 5.6	25.6±5.5	40.6±4.3	56.4±6.3	37.6±5.7	43.8±6.5	
	Mean	33.9	26.5	39.2	54.8	36.9	43.1	
Doi et al. (31)	X-rays	-	-	-	-	34.6	38.4	

*The quadrant method of Bernard and Hertel (13) as in Figure 1 was used for the femoral footprint and the Amis and Jakob's methods (13) as in Figure 2 for the tibial footprint except where noted. AM, anteromedial bundle; PL, posterolateral bundle;

a, height, b, depth on the lateral femoral condyle; X-rays, radiographs; CT-scan, computed tomography scan position is close to that found by different authors (14,21,23), and shallower than those found by others (17,30).

The centre of tibial tunnel in the SB group was located at 44.5±6% of the tibial plateau length. Musahl et al. found the same location for the entire ACL tibial footprint; differences between radiographs and CT-scan evaluation were not statistically significant (27). De Abreu-e-Silva et al. found it to be located at 40.5±5.3% in the AP direction, on 3D CT-scan with a reference consistent with the radiographic method of Amis and Jakob) (28).

In the present study, the centre of tibial AM tunnel in the DB group was located at 40.5±4% of depth, that is a more posterior position than reported by other authors (14,30,31). A 5% difference was found, corresponding to about 2.5 mm as absolute value in Colombet's (14) and Doi's samples (31); in our opinion this was due to the use the 65° Howell guide that tends to locate the tibial tunnel more posteriorly to prevent roof impingement in extension Cuomo et al(32). Iriuchishima et al. (21) and Zantop et al. (17) found a more anterior location for the centre of the tibial AM footprint; anyway, they determined the centre of the tunnels according to the technique described by Stäubli and Rausching (33) that uses a different reference to define the maximum tibial sagittal diameter.

In the DB group, the centre of PL bundle was located at 51.5±4% of the tibial sagittal diameter, in line with the studies of Colombet et al. (14) and Pietrini et al. (30), while Doi et al. (31) found it to be more anterior. This could be related to the large variation in tibial insertion patterns of AM and PL bundles (14,15,34). Also, differences between all these studies can be due to the small number of knees analysed in every cadaveric study, to different insertion patterns of AM and PL native bundles (11,14,15,34) and to anatomical differences which can be found in individuals of various ethnicities (having been the studies performed in different continents).

Colombet et al. found that the distance between the centre of AM and PL bundles was 8.2±1.2 mm on femoral side and 8.4±0.6 mm on tibial side (14), while Lee et al. found such distance to be 6.4±1.2 mm and 6.2±1 mm for femoral and tibial attachments, respectively (23). Edwards et al. found that the distance between the centre of AM and PL bundles on femoral side was 8±1.3 mm, while the distance on the tibial side could be extrapolated in 7 mm (11,34). With regard to the femoral side, Zantop et al. found the distance between bundles to be 8-10 mm (17), while Tashiro et al. superimposed the anatomical information obtained by previous authors onto 3D CT-scan models and found that the distance between AM and PL centres could be evaluated 10.2±0.6 mm in males and 9.4±0.5 mm in females (35). Our prototype rod-guide was designed to locate the centre of the PL bundle at the fixed distance from the centre of the AM bundle of 9 mm on femur and 8 mm on the tibia. This distance seems therefore to be 1 mm excessive with respect to data from cadaveric studies, but it was chosen as a safe standard distance to secure a bony bridge of 2 mm between tunnels with a 6-mm diameter, taking into account possible ovalization of the tunnel aperture as well (6).

The second finding of this study is the intra- and inter-observer reliability of tunnel evaluation on radiographs using two simple methods of measurement. With respect to the quadrant method for the femur, intra-observer reliability was quoted almost perfect for the SB group and PL tunnel in the DB group, and substantial for AM tunnel in the DB group; inter-observer reliability was almost perfect for the SB group and substantial for both AM and PL tunnels in the DB group. With respect to Amis and Jakob's method for the tibial tunnel(s), intra-observer reliability was almost perfect either in the SB group and the DB group for both tunnels, whereas inter-observer reliability was almost perfect in the SB group and substantial in the DB group for both tunnels. Colombet et al. calculated the inter-observer error in millimetres but did not calculate the ICC (14). Doi et al. measured twice the landmarks but did not evaluate any intra- or inter-observer variability (31). Pietrini et al. instead found an excellent reliability (ICC ≥ 0.989 in all analyses) either for intra-observer and inter-observer measurements (30). Anyway, their excellent reliability was due to the preparation of cadaveric knees (dissected free from soft tissues except for ACL, menisci and collateral ligaments), the use of 2-mm stainless steel spheres to label the centres of the bundles, the marking of AM and PL footprints with a radio-opaque barium sulphate emulsion. With such a preparation, intra- and inter-observer variability related only to generate reference lines and to measure distances.

In the present study, each observer had to "find" the tunnel(s)' centre on radiographs *in vivo*, to generate reference axes and to measure distances; it was therefore a multiple-step measuring which may amplify errors. Nevertheless, the reliability was graded "almost perfect" for the SB group and at least "substantial" for the DB group. This may be due to the fact that tunnel apertures in the DB group were smaller and superimposed each other, making them more difficult to be detected. To bypass such a problem, Horie et al. proposed a modified quadrant method technique (22). They first calculated the position of femoral tunnels on a Rosenberg view, then reported the lines over the lateral view respecting the calculated height ratios and then drawn the axes of the femoral tunnels up to the intersection with these horizontal lines to obtain the position of tunnel apertures relatively to depth. They found this method to have excellent intra-observer reliability, almost perfect inter-observer reliability for AM tunnel and substantial inter-observer reliability for PL tunnel. Also, the accuracy of the method was found to be almost perfect comparing it to 3D CT-scan. In the present series, it was not possible to identify femoral tunnel apertures on the lateral view in only 2 over 30 cases in DB-group. Moreover, the modified quadrant method proposed by Horie et al. (22) requires a Rosenberg view and a careful reporting of the horizontal lines on the lateral view as a ratio.

There are several limitations in this study. First, radiographic analysis was performed only on lateral radiographs, even if AP radiographs were available, and a CT-scan and/or MRI study should also have been performed. Studying only the lateral view can be enough to evaluate the tunnel(s) position on the femur, while it gives only depth on the tibia: for practical purposes, it seems sufficient to collect such data (31). As for the femoral side, there is a need to evaluate tunnel(s) position on 2 axes (height, depth), and this can be done on lateral radiographs, while the third axis (width) is obviously on the medial wall of the LFC. Nevertheless, methods to evaluate femoral tunnel(s) position on AP radiographs have been proposed. The clock method, which is used intra-operatively to evaluate where to put the tunnel(s), (5) is neither a pure axial nor a coronal view of the notch, it can be evaluated on 3D CT-scan or 3D MRI or even radiographically but only in cadaveric dissected knees (29), while it is not possible to get an adequate axial imaging *in vivo*. The Rosenberg view has been described as useful to evaluate the height of the tunnel (22), and a modified clock evaluation on the same view has been proposed (36), but such an imaging of the distal femur is not actually mimicking the arthroscopic view, it lacks further usefulness and can create confusion with arthroscopic nomenclature. As for the tibia, anatomical landmarks have been well known since the 1990s (12) and they are clearly evident intra-operatively to locate the tunnel(s). Also, a CT-scan and/or MRI study was not performed, which would have added more precise data on the tunnel(s) position both on the tibia and the femur; anyway, radiograph analysis seems to be reliable and reproducible when compared with 3D CT-scan (20–23).

The second limitation is that current results could not be compared with data about ACL footprints obtained on cadaveric specimens by same authors (15,32), and only to the limited number of mentioned studies because of different methods used to evaluate native ACL footprints and tunnel position. In previous papers (15), the circle method (37) had been used to measure the position of the tunnels on the femoral side, but the quadrant method (24) seems to be easier and more used nowadays. In our opinion, this is currently and actually the main issue that needs to be addressed, as different methods and modification of historical methods are being proposed, each of which has advantaged and disadvantages, and even if they seem to be tantamount, they are not.

The third limitation of this study is that a correlation between the tunnel position and clinical results was not evaluated; it would be interesting to understand if a particular position would have led to a slack ACL (increased AP or rotational laxity).

In conclusions, the quadrant method of Bernard and Hertel for the femoral side and the Amis and Jakob's method for the tibial side are reliable, useful and easy methods for radiographic description of the tunnel position. A universal consensus on radiographs views, methods of evaluation and nomenclature are deemed appropriate to improve opportunity of comparison between studies. Also, it can be postulated that anatomical landmarks are useful and sufficient to locate the tunnel(s) on the tibial side, while on the femoral side anatomical landmarks are less clearly evident and have to be integrated with data obtained by radiographic and cadaveric measurements.

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TRANSPARENCY DECLARATION

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