Knee Surg Sports Traumatol Arthrosc (2010) 18:1599–1606
DOI 10.1007/s00167-010-1189-y

KNEE

Postoperative evaluation of tibial footprint and tunnels characteristics after anatomic double-bundle anterior cruciate ligament reconstruction with anatomic aimers

Amit Sahasrabudhe · Pascal Christel · Francois Anne · David Appleby · Georges Basdekis

Received: 29 January 2010 / Accepted: 25 May 2010 / Published online: 29 June 2010

Abstract Following anatomic double-bundle anterior cruciate ligament (ACL) reconstruction with hamstring tendon autografts, 38 consecutive patients were evaluated with high-speed three-dimensional computed tomography. Scans were performed within 3 days following surgery. The length and width of the reconstructed ACL footprint were measured on axial images. Then, 3D images were converted into 2D with radiologic density for measurement purposes. Tunnel orientation was measured on AP and lateral views. In the sagittal plane, the center of the anteromedial (AMB) and posterolateral bundle (PLB) tibial attachment positions was calculated as the ratio between the geometric insertion sites with respect to the sagittal diameter of the tibia. In addition, the length from the anterior tibial plateau to the retro-eminence ridge was measured; the relationship of this line with the centers of the AM and PL tunnels was then measured. The AP length of the reconstructed footprint was 17.1 mm ± 1.9 mm and the width 7.3 mm ± 1.2 m. The distance from retro-eminence ridge to center of AM tunnel was 18.8 mm ± 2.8 mm, and the distance from RER to center of PL tunnel was 8.7 mm ± 2.6 mm. The distance between tunnels center was 10.1 mm ± 1.7 mm. There were no significant differences between the intra- and inter-observer measurements. The bone bridge thickness was 2.1 mm ± 0.8 mm. In the sagittal plane, the centers of the tunnel apertures were located at 35.7% ± 6.7% and 53.7% ± 6.8% of the tibia diameter for the AMB and PLB, respectively. The surface areas of the tunnel apertures were 46.3 mm^2 ± 4.4 mm^2 and 36.3 mm^2 ± 4.0 mm^2 for the AM and PL tunnels, respectively. The total surface area occupied by both tunnels was 82.6 mm^2 ± 7.0 mm^2. In the coronal plane, tunnel orientation showed the AM tunnel was more vertical than the PL tunnel with a 10° divergence (14.8° vs. 24.1°). In the sagittal plane, both tunnels were almost parallel (29.9° and 25.4° for the AM and PL tunnels, respectively). When using anatomic aimers, the morphometric parameters of the reconstructed tibial footprint in terms of length and distances to the surrounding bony landmarks were similar to the native ACL tibial footprint. However, the native footprint width was not restored, and the surface area of the two tunnel apertures was in the lower range of the published values for the native footprint area.

Keywords Anterior cruciate ligament · Anatomic ACL reconstruction · Ancillary instruments · 3D CT scan · Tibial tunnel position

A. Sahasrabudhe
Arizona Sports Medicine Center,
5111 N Scottsdale Rd, Scottsdale,
AZ 85250, USA

P. Christel (✉)
Sports Medicine, Habib Medical Center Olaya,
PO Box 91877, Riyadh 11643, Saudi Arabia
e-mail: pascal.christel485@gmail.com

F. Anne
Imaging Department, Paul d'Egine Hospital,
1 Avenue Marx Dormoy,
94500 Champigny s/Marne, France

D. Appleby
Smith & Nephew Endoscopy,
150 Minuteman Road, Andover, MA 01810, USA

G. Basdekis
University Hospital of Larissa,
Department of Orthopaedics,
University of Thessalia,
Mezourlo, 41110 Larissa, Greece

Introduction

Single-bundle anterior cruciate ligament (ACL) reconstruction remains the most widely performed surgical technique for ACL surgery. Most of the published literature on ACL reconstruction has reported a 70–90% patient outcome success rate; however, 10–30% of patients continue to experience persistent knee pain and instability [4, 10, 20, 25, 34]. Yagi et al. [34] reported that single-bundle reconstruction produces an abnormal biomechanical outcome, especially during rotatory loads when compared to double-bundle reconstruction. In laboratory studies and in clinical outcome studies, various authors have demonstrated that double-bundle ACL reconstruction results in better rotational stability than single-bundle ACL reconstruction [7, 10, 22, 34]. Thus, interest in surgical techniques that reconstruct both bundles of the ACL has risen, and a variety of anatomic double-bundle ACL reconstruction techniques now exist [5, 12, 17, 19].

Knowledge of the anatomy of these bundles and their attachment sites is critical when performing anatomic ACL reconstruction and has been studied in detail [6, 14, 28, 31, 36]. However, it has been shown that arthroscopic surgeons may have difficulty in accurately placing the drill holes for single-bundle reconstruction despite rigorous training [6].

Difficulty in tunnel placement has created the need for techniques to reliably reproduce and reference the positions of the bundles from consistent landmarks, both on the femoral and the tibial sides [6]. However, most articles published in the literature have addressed the issue of the femoral tunnels, while few have investigated tibial tunnels placement. Several studies have described various landmarks for tibial tunnel referencing [6, 9, 14–16, 24, 30–32], and quantitative data specific to anatomic double-bundle ACL reconstruction have recently been made available [6, 12, 28, 30, 31].

The purpose of this study was to investigate the positioning of tibial anteromedial (AM) and posterolateral (PL) tunnels and morphometry of the footprint using high-speed 3D computed tomography (3D CT), following anatomic double-bundle ACL reconstruction performed with specific instrumentation. The hypothesis was that using specific instrumentation, it was possible to reproduce the characteristics of the tibial ACL footprint in terms of size, position with regard to anatomic landmarks, and surface area. A secondary aim was to investigate tunnel orientation in both coronal and sagittal planes and to compare with the results of the literature.

Materials and methods

Anatomic double-bundle ACL reconstruction with hamstring tendon autografts was performed using the Smith & Nephew ACUFEX Director Set for Anatomic ACL Reconstruction [5] according to the surgical technique summarized below. The harvest step of hamstring tendons is identical to that of a single-bundle hamstring graft. A double-stranded gracilis (Gr) tendon and a double-stranded semitendinosus (ST) are fashioned. Each graft is slipped through an EndoButton^{TM} CL (Smith & Nephew, Mansfield, MA). The ST graft is used for the anteromedial bundle (AMB) reconstruction while the Gr replaces the posterolateral bundle (PLB).

The arthroscopic reconstruction is based on the use of a three-portal technique: anterolateral (AL), anteromedial (AM), and accessory anteromedial [Christel]. With the scope through the main AM portal, the centers of both femoral AM and PL bundles are marked with an RF probe introduced through the AAM portal. The femoral tunnels are drilled first starting with the anteromedial tunnel. With the knee bent between 110° and 120° of flexion, keeping the scope through the AM portal, an Endofemoral aimer (Smith & Nephew, Mansfield, MA) is introduced through the AAM portal guiding a 2.4-mm guide wire through the center of the AM bundle. A cannulated 4.5-mm drill bit is advanced over the pin and breaches the lateral femoral cortex. The total length of the AM femoral tunnel is then measured, and an AM socket is drilled at a depth depending on both the tunnel and the Endobutton^{TM} CL length.

The Anatomic Posterolateral Femoral aimer (Smith & Nephew, Mansfield, MA) is then introduced through the AAM portal. Keeping the knee bent between 120° and 130° of flexion [8], the tip of the aimer is introduced in the AM socket, and the laser mark of the aimer's bullet aligned with the center of the PL bundle previously marked. A 4.5-mm solid drill bit is then drilled through the lateral femoral cortex. The length of the PL tunnel is measured, and the appropriate PL socket is created. Thus, two sockets diverging by 15° have been created with a 1.5 to 2.5-mm bony bridge in between.

On the tibial side, with the scope inserted through the AL portal, the centers of the anatomic insertions of the AMB and PLB, according to known bony landmarks, are marked with an RF probe. The knee is bent at 90°, and the Director tibial guide (Smith & Nephew, Mansfield, MA) with the bullet oriented at 60° to the joint line is introduced into the joint through the AM portal. The tip of the guide is positioned on the center of the anatomic attachment area of the native AMB. The 2.4-mm guide wire starting from the medial edge of the tibial tubercle is advanced until it emerges at the desired location. A cannulated drill bit undersized by 1 mm is advanced into the joint, and dilators are used to expand the tunnel to the final diameter identical to the graft diameter.

The Anatomic PL tibial guide (Smith & Nephew, Mansfield, MA) consists of interchangeable posts fitting the AM tunnel and a lateral flange with a bullet. Once inserted into the AM tunnel, the distal end of the post is flush with the tibial surface. The AM post is rotated until the slot at its tip is aligned with the center of the PLB. The tip of the bullet is located on the anterior edge of the superficial fibers of the medial collateral ligament. Once acceptable placement of the 2.4-mm drill tip guide is obtained, a 1-mm undersized cannulated drill bit is advanced into the joint space, and the tunnel is finally dilated to its final diameter. An osseous bridge of 2–3 mm remains between the two tunnels inside the joint. On the outer tibial surface, the distance between the tunnels apertures is 15–20 mm.

The PL graft is passed first followed by the AM graft. Endobuttons are flipped on the lateral femoral cortex, and tibial fixation is performed with bioabsorbable interference screws under 30–40N tension.

Following surgery, 38 consecutive patients were evaluated with high-speed CT scan (General Electric Volume Viewer, General Electric, Waukesha, Wisconsin). Scans were performed within 3 days of surgery. Three-dimensional reconstruction of the postoperative knee was performed using the volume rendering technique (Fig. 1). This technique allows for digital subtraction of the femur and all soft tissue, while rotating the image into the axial view [3, 26]. First, the length and width of the footprint were measured on axial images. The centers of the AM and PL tunnels (CAM and CPL) were then marked. The length from the anterior tibial plateau to the retro-eminence ridge (RER) [6], called "over-the-back ridge" by Mc Guire et al. [23], was measured. The relationship of this ridge (hereafter noted as RERA) with the CAM and CPL was noted. Keeping the centers of each tunnel marked, the 3D axial image was then converted to a radiographic image (a feature of the GE Volume Viewer 2) and rotated into the coronal and lateral views. On lateral view, the position of the line described by Stäubli and Rauschning [29] was marked and the length measured. Points CAM and CPL were then projected onto this line, allowing the positions of both bundles to be described in terms of a percentage length of the line (Fig. 2): 0% meant intersection with the anterior cortex, while 100% meant intersection with the posterior cortex.

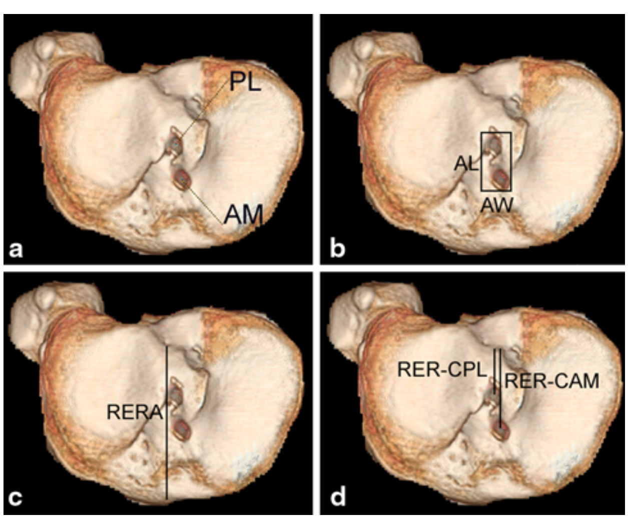

Fig. 1 **a–d** Morphometric parameters measured on the 3D CT axial view of the tibia (see text for the abbreviations)

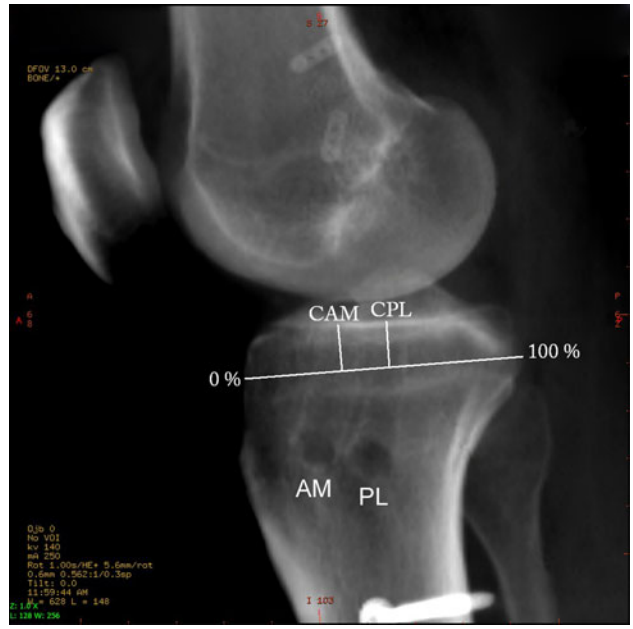

Fig. 2 Morphometric parameters measured on the 2D converted lateral view of the tibia. For each tunnel, the center of the intraarticular aperture (*CAM*, *CPL*) is projected on the Stäubli and Rauschning line. The position of the projection is expressed in percentage of the *line length*

All ACL reconstructions were performed by the senior author (P. Christel). Two different examiners (A. Sahasrabudhe & G. Basdekis), both orthopedic surgeons, trained by a radiologist and independent from the surgeon who performed surgery, made two separate and independent measurements of each knee. Following is a summary of all measurements recorded:

Axial 3D tibia images

- Length of reconstructed ACL footprint (AL)
- Width of reconstructed ACL footprint (AW)
- Center of anteromedial tunnel (CAM)
- Center of posterolateral tunnel (CPL)
- Distance between tunnel centers (TCD)
- Bone bridge thickness between tunnels (BB)
- Distance from RER to anterior plateau (RERA)
- Distance from RER to center of anteromedial tunnel (RER-CAM)
- Distance from RER to center of posterolateral tunnel (RER-CPL)
- Surface area of the tunnel apertures

Lateral 3D tibia radiographs

- AP diameter of the tibia (length of the Stäubli and Rauschning line) (AP)
- Distance from anterior cortex to projection of line from center of anteromedial tunnel (AP-CAM)
- Distance from anterior cortex to projection of line from center of posterolateral tunnel (AP-CPL)

The converted 2D radiographic images were used to measure the tibial tunnels orientation in the frontal and sagittal plane, as described by Kondo et al. [19]. For each tunnel, the tunnel angle was defined as the angle between the tunnel axis and the long axis of the tibia. The tunnel axis was defined as a line passing the 2 central points of the intra-articular outlet and the extra-articular outlet. The long axis of the tibia was defined as the long axis of the diaphysis of the tibia, which could be measured on each converted 2D radiographic image (Fig. 3).

Statistical analysis

Descriptive statistics were used to describe the orientation and position of the tibial tunnels. A multiple regression analysis was used to assess intra-observer and inter-observer reliability in the measurement of orientation and position of the tibial tunnels. Pearson correlation coefficients were calculated to quantify intra-observer and inter-observer reliability, and 95% confidence intervals were constructed to compare measurements of the present study to the results of previous studies [6, 28]. Confidence intervals that do not overlap correspond to a *P* value less than 0.05. Statistical analyses were performed using SAS version 9.1.3 (Cary, NC, USA).

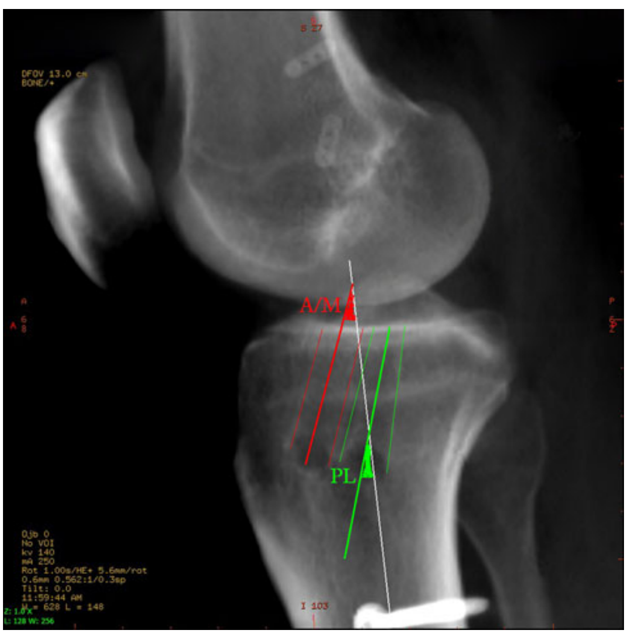

Fig. 3 The tunnel angle was defined as the angle between the tunnel axis and the long axis of the tibia. The tunnel axis was defined as a *line passing the 2 central points* of the intra-articular outlet and the extra-articular outlet. The long axis of the tibia was defined as the long axis of the diaphysis of the tibia, which could be measured on each converted 2D radiographic image

Results

The overall morphometric measurements of the reconstructed footprint are described in Table 1. Multiple regression analysis demonstrated high intra-observer and inter-observer reliability. The measurements did not differ based on which surgeon was taking the measurements or whether it was the first or second measurement taken for a sample. Pearson correlation coefficients for each measurement showed that the measurements were independent of surgeon and whether it was the first or second measurement. All coefficients were extremely small with corresponding *P* values greater than 0.9.

The average AP diameter of the tibia was 55 mm ± 4.2 mm. The distance from the anterior cortex to the projection of a line from the center of the AM tunnel was 19.8 mm ± 4.0 mm, corresponding to 35.7% ± 6.7% of the AP diameter. The distance from the anterior cortex to the projection of a line from center of PL tunnel was 29.5 mm ± 3.9 mm, corresponding to 53.7% ± 6.8% of the AP diameter.

During surgery, the diameter range of the drill bit used for tunnel drilling was 6–8 mm and 6–7 mm for the AM and PL tunnels, respectively. Thus, the resulting average tunnel diameter in the sagittal plane was 7.0 mm ± 0.4 mm for the AM tunnel and 6.2 mm ± 0.3 mm for the PL tunnel. Due to the tunnel obliquity, the intra-articular tunnel aperture has an elliptic shape, and the surface area of the AM tunnel was 46.3 mm^2 ± 4.4 mm^2 and 36.3 mm^2 ± 4.0 mm^2 for the PL tunnel. The total surface area occupied by both tunnels was 82.6 mm^2 ± 7.0 mm^2.

On converted 2D radiographic images, the tibial tunnel angles of the PL bundle averaged 24.1° ± 5.5° (mean ± SD) in the AP view and 25.4° ± 5.3° in the lateral view. The tibial tunnel angles of the AM bundle averaged 14.8° ± 5.0° in the AP view and 29.9° ± 4.5° in the lateral view. There was a 10° divergence between the two tunnels on the AP view and 4° on the lateral view, the AM tunnel being more vertical than the PL tunnel in both planes.

Table 1 Results of 3D CT measurements of the tunnel apertures morphometry on the axial plane

Morphometric parameters (mm)	Mean ± SD	Ratio to RERA (%)
Footprint length (AL)	17.1 ± 1.9	–
Footprint width (AW)	7.3 ± 1.2	–
Distance from the RER to anterior plateau limit (RERA)	29.9 ± 3.0	–
Distance from the RER to AM tunnel center (RER-CAM)	18.8 ± 2.8	62.5
Distance from the RER to PL tunnel center (RER-CPL)	8.7 ± 2.6	28.4
Distance between tunnel centers (TCD)	10.1 ± 1.7	–
Bone bridge thickness (BB)	2.1 ± 0.8	–

AM anteromedial, *PL* posterolateral, *RER* retroeminence ridge

Discussion

The most important finding of the current study is that, in accordance with our initial hypothesis, it was feasible with the current instrumentation to position and keep the AM and PL tunnel apertures within the native ACL tibial footprint saving a bone bridge between the two tunnel apertures.

The purpose of this study was to carry out an assessment of the tibial tunnel position right after surgery and correlation with clinical outcome would need a longer follow up. However, clinical outcome depends among others on both femoral and tibial position, and it is difficult to isolate the effect of tibial positioning only. It has been made possible to quantify the positioning of both AM and PL tibial tunnels by using high-speed 3D CT scan coupled with the volume rendering technique. This technique allows one to obtain accurate measurements of the ACL footprint characteristics [25] and has also been used to characterize the femoral tunnel positioning in double-bundle ACL reconstruction with regard to the native ACL attachment site [2].

Strength of our study includes the absence of significant inter- and intra-observer error differences. There is slight variation of error in CT measurements taken. Purnell et al. [26] have calculated their possible error to be ± 0.3 mm. Our intra-observer error for length measurement was also ± 0.3 mm which is lower than the intra-observer measurement from cadaveric studies [6]. One may consider one weakness of this study is the lack of clinical follow-up. However, aim of this study was to provide a method to validate the postoperative position of the tibial tunnels after anatomic double-bundle ACL reconstruction. In the field of scientific studies, we advocate tunnel positioning should be objectively documented before publishing any ACL reconstruction outcome, and in this respect 3D CT scan is an accurate method for this. Basdekis et al. [2] have previously published their method for evaluation of femoral tunnel position using 3D CT scan which could be combined with the methodology of this study in order to assess global tunnel positions after ACL reconstruction.

The insertion site for the ACL on the tibia is located in the area between the medial and lateral tibial spines. In this region, the fiber bundles of the ACL fan out and form the

Table 2 Results of the present study fit those of literature [6, 28]

Measurement	Present study			Colombet et al. [6]			Siebold et al. [28]		
	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI
AL*	17.1	16.8	17.4	17.6	16.0	19.2	14	13.4	14.6
AW**	7.3	7.1	7.5	12.7	10.6	14.8	10	9.4	10.5
AP	55.0	54.3	55.7	55.4	50.3	60.5			
CAM	36%	34.9	37.1	36%	33.2	38.8			
As percentage of the tibia diameter									
CPL	54%	52.9	55.1	52%	49.5	54.4			
As percentage of the tibia diameter									
RERCAM	18.8	18.4	19.3	17.5	16.1	18.9			

For comparison, we used the mean values and the lower and upper 95% confidence intervals

AL length of reconstructed ACL footprint, *AW* width of reconstructed ACL footprint, *AP* length of the Stäubli and Rauschning's line, *CAM* center of anteromedial tunnel projected on the line, *CPL* center of posterolateral tunnel projected on the line, *RERCAM* distance from RER to center of anteromedial tunnel

* $P < 0.05$ for the comparison of AL between the present study and Siebold et al. [28]

** $P < 0.05$ for all comparisons of AW

so-called duck-foot region. Similar to our results, others have shown the average length of this area to be approximately 17 mm and the width approximately 9–11 mm [1, 8, 11, 12, 28, 31, 36]. However, the width of the reconstructed foot print was 7.3 mm ± 1.2 m, significantly less than the native ACL (Tables 2 and 3).

The average distance between both tunnel centers may vary between 5 and 8 mm [6, 28]. The variations are related to knee size, gender, and the shape of the bundle footprint which is not circular making difficult the appreciation of the bundle center. When considering the 95% confidence interval, the average tibial insertion area has been measured by several authors ranging between 78 and 169 mm^2 [14, 28], and we found a surface area ranging between 75.6 and 89.6 mm^2, values which are in the lower part of the interval (Table 3). Moreover, if the graft diameter corresponds to the one of the tunnel, the tendons do not fully fill the tunnel aperture. Thus, the technique with double-stranded double-bundle hamstring autograft does not fully reproduce the surface ACL tibial footprint area, at least in big knees, mostly since the correlation between the graft diameter and the patient's biometric parameters is weak [27, 32]. Maybe the use of bigger allografts may compensate for this weakness [33]. However, there is space limitation if one wants to save a bone bridge between the two tunnels.

Comparison of the results of the current study with similar data drawn from literature [6, 9, 14, 26, 28, 29] shows similar values (Table 3). We have chosen to put an emphasis on the RER as an important bony landmark as it has been shown by several authors [9, 15] that measurements based on the medial tibial eminence were particularly erratic. They found the most reproducible anatomic landmark was the RER position. Our findings also agree with data published by Edwards et al. [9] who revealed tibial center of the AMB at 17 ± 2 mm from the RER, whereas their PLB center location was at 10 ± 1 mm from the RER. However, our values cannot be directly compared with those of Hutchinson and Bae [15], who considered only the posterior limit and the center of the ACL tibial footprint, without considering the bundle centers or the anterior limit of the footprint.

Regarding the projection of the bundle centers on the AP tibial diameter, Table 2 shows the results of previous anatomic and radiologic studies when compared to ours. We found the position of our tunnels centers similar to the position of the bundles centers published by others [6, 18, 21, 35].

However, Edwards et al. [9] and Zantop et al. [35] described more anteriorly located tibial insertions of the two bundles. As already stated above, because of the insertion sites of the AMB and PLB are not circular [21], the definition of the center of the bundles can be difficult to determine.

Table 3 Results of the present study compared with those of literature, for tibial footprint length, width, and surface areas (mean ± SD)

	Material and methods	*N*	Length (mm)	Width (mm)	Surface area (mm^2)	AMB surface area (mm^2)	PLB surface area (mm^2)
Colombet et al. [6]	Cadaver vernier caliper	7	17.6 ± 2.1 (15.5–19.7)	12.7 ± 2.8 (9.9–15.5)	–	–	–
Siebold et al. [28]	Cadaver digital photos	50	14 ± 2 (12–16)	10 ± 2 (8–12)	114 ± 36 (78–150)	67 ± 31 (36–98)	52 ± 30 (32–72)
Edwards et al. [9]	Cadaver digital photos	55	18 ± 2 (16–20)	9 ± 2 (7–11)	–	–	–
Stäubli and Rauschning [29]	Cadaver cryosection	10	15 ± 4 (11–19)	–	–	–	–
Harner et al. [14]	Cadaver laser micrometer	5	–	–	136 ± 33 (103–169)	56 ± 21 (33–77)	53 ± 21 (32–74)
Purnell et al. [26]	CT scan volume rendering	8	10.7 ± 1.3 (9.4–12)	7.4 ± 1.2 (6.2–8.6)	–	–	–
Current study	CT scan volume rendering	38	17.1 ± 1.9 (15.2–19)	7.3 ± 1.2 (6.1–8.5)	82.6 ± 7 (75.6–89.6)	46.3 ± 4.4 (41.9–50.7)	33.3 ± 4.0 (32.3–40.3)

Lower and upper 95% confidence intervals are indicated between parentheses

SDs are higher for cadaver measurements compared to CT scan

Hantes et al. [13] have compared the tibial tunnel orientation using either the transtibial or the transportal technique in drilling the femoral tunnels. They did not find significant differences in tibial tunnel orientation when comparing transtibial or transportal technique. Few studies of tibial tunnels orientation in anatomic double-bundle reconstruction have been published. Kondo et al. [19] reported that the tibial tunnel angles of the PL bundle averaged 40.7° on the AP view and 35.4° on the lateral view. We found narrower tibial tunnel angles for the PL bundles. On the anteroposterior view, we report an angle of 24.1°, while on the lateral view an angle of 25.4°. Kondo et al. [19] reported the tibial tunnel angles of the anteromedial bundle averaged 15.6° in the AP view and 41.4° on the lateral view. We found a similar angle on the AP view of the AM bundle and a more vertical angulation on the lateral view. On the AP view, we report an angle of 14.8° and on the lateral view an angle of 29.9°. However, Kondo et al. [19] drill their femoral tunnel transtibially, contrary to the technique used in the current study. This difference in technique may account for the differences in tunnel angles.

The current results demonstrate the tibial anatomic aimer used in this study allows to position the tibial tunnels always inside the limits of the ACL tibial footprint. In this series of 38 patients, no case of intra-operative tunnel merging has ever been observed. A 2-mm bone bridge separating the tunnel apertures was always present making this instrumentation safe.

Conclusion

In the current study, the use of 3D CT scan was able to demonstrate that the morphometric parameters of the reconstructed tibial footprint in terms of length and distances to the surrounding bony landmarks were similar to the native ACL. However, the width of the reconstructed footprint was significantly less than the native ones. Also, the value of the surface area of the two tunnels aperture was situated in the lower range of the native footprint.

References

1. Arnoczky SP (1983) Anatomy of the anterior cruciate ligament. Clin Orthop Relat Res 172:19–25
2. Basdekis G, Pascal Christel P et al (2009) Validation of the position of the femoral tunnels in anatomic double-bundle ACL reconstruction with 3-D CT scan. Knee Surg Sports Traumatol Arthrosc 17:1089–1094
3. Basdekis G, Abisafi C, Christel P (2009) Effect of knee flexion angle on the length and orientation of posterolateral femoral tunnel drilled through the anteromedial portal during anatomic double-bundle ACL reconstruction. Arthroscopy 25:1108–1114
4. Chhabra A, Starman JS, Ferretti M et al (2006) Anatomic, radiographic, biomechanical, and kinematic evaluation of the anterior cruciate ligament and its two functional bundles. J Bone Joint Surg (Am) 88(S-4):2–10
5. Christel P, Sahasrabudhe A, Basdekis G (2008) Anatomic double-bundle anterior cruciate ligament reconstruction with anatomic aimers. Arthroscopy 24:1146–1151
6. Colombet P, Robinson J, Christel P et al (2006) Morphology of anterior cruciate ligament attachments for anatomic reconstruction: a cadaveric dissection and radiographic study. Arthroscopy 22:984–992
7. Colombet P, Robinson J, Christel P et al (2007) Using navigation to measure rotation kinematics during ACL reconstruction. Clin Orthop Relat Res 454:59–65
8. Dienst M, Burks RT, Greis PE (2002) Anatomy and biomechanics of the anterior cruciate ligament. Orthop Clin North Am 33:605–620
9. Edwards A, Bull AMJ, Amis AA (2007) The attachments of the anteromedial and posterolateral fibre bundles of the anterior cruciate ligament. Part 1: tibial attachment. Knee Surg Sports Traumatol Arthrosc 15:1414–1421
10. Georgoulis AD, Ristanis S, Moraiti C et al (2005) Three-dimensional kinematics of the tibiofemoral joint in ACL deficient and reconstructed patients shows increased tibial rotation. Oper Tech Orthop 15:49–56
11. Girgis FG, Marshall JL, Monajem A et al (1975) The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. Clin Orthop 106:216–231
12. Giron F, Cuomo P, Edwards A et al (2007) Double-bundle "anatomic" anterior cruciate ligament reconstruction: a cadaveric study of tunnel positioning with a transtibial technique. Arthroscopy 23:7–13
13. Hantes ME, Zachos VC, Liantsis A et al (2009) Differences in graft orientation using the transtibial and anteromedial portal technique in anterior cruciate ligament reconstruction: a magnetic resonance imaging study. Knee Surg Sports Traumatol Arthrosc 17:880–886
14. Harner CD, Baek GH, Vogrin TM et al (1999) Quantitative analysis of human cruciate ligament insertions. Arthroscopy 15:741–749
15. Hutchinson MR, Bae TS (2001) Reproducibility of anatomic tibial landmarks for anterior cruciate ligament reconstructions. Am J Sports Med 29:777–780
16. Jackson DW, Gasser SI (1994) Tibial tunnel placement in ACL reconstruction. Arthroscopy 10:124–131
17. Järvelä T (2007) Double-bundles versus single-bundle anterior cruciate ligament reconstruction: a prospective, randomized clinical study. Knee Surg Sports Traumatol Arthrosc 15:500–507
18. Kasten P, Szczodry M, Irrgang J et al (2010) What is the role of intra-operative fluoroscopic measurements to determine tibial tunnel placement in anatomical anterior cruciate ligament reconstruction? Knee Surg Sports Traumatol. doi 10.1007/s00167-010-1082-8 (epub ahead of print)
19. Kondo E, Yasuda K, Ichiyama H et al (2007) Radiologic evaluation of femoral and tibial tunnels created with the transtibial tunnel technique for anatomic double-bundle anterior cruciate ligament reconstruction. Arthroscopy 23:869–876
20. Lewis PB, Parameswaran D, Rue JPH et al (2008) Systematic review of single-bundle anterior cruciate ligament reconstruction outcomes: a baseline assessment for consideration of double-bundle techniques. Am J Sports Med 36:2028–2036
21. Lorenz S, Eklser F, Mitterer M et al (2009) Radiologic evaluation of the insertion sites of the 2 functional bundles of the anterior cruciate ligament using 3-dimensional computed tomography. Am J Sports Med 37:2368–2376

22. Markolf KL, Park S, Jackson SR et al (2009) Anterior-posterior and rotatory stability of single and double-bundle anterior cruciate ligament reconstructions. J Bone Joint Surg (Am) 91:107–118
23. McGuire DA, Hendricks SD, Sanders HM (1997) The relationship between anterior cruciate ligament reconstruction tibial tunnel location and the anterior aspect of the posterior cruciate ligament insertion. Arthroscopy 13:465–473
24. Morgan CD, Kalman VR, Grawl DM (1995) Definitive landmarks for reproducible tibial tunnel placement in anterior cruciate ligament reconstruction. Arthroscopy 11:275–288
25. Peterson W, Zantop T (2006) Anatomy of the anterior cruciate ligament with regard to its two bundles. Clin Orthop Relat Res 454:35–47
26. Purnell ML, Larson AI, Clancy W (2008) Anterior cruciate ligament insertions on the tibia and femur and their relationships to critical bony landmarks using high-resolution volume-rendering computed tomography. Am J Sports Med 36:2083–2090
27. Schwartzberg R, Burkhart B, Lariviere C (2008) Prediction of hamstring tendon autograft diameter and length for anterior cruciate ligament reconstruction. Am J Orthop 37:157–159
28. Siebold R, Ellert T, Metz S et al (2008) Tibial insertions of the anteromedial and posterolateral bundles of the anterior cruciate ligament: morphometry, arthroscopic landmarks, and orientation model for bone tunnel placement. Arthroscopy 24:154–161
29. Stäubli HU, Rauschning W (1994) Tibial attachment area of the anterior cruciate ligament in the extended knee position. Anatomy and cryosections in vitro complemented by magnetic resonance arthrography in vivo. Knee Surg Sports Traumatol Arthrosc 2:138–146
30. Takahashi M, Doi M, Abe M et al (2006) Anatomical study of the femoral and tibial insertions of the anteromedial and posterolateral bundles of human anterior cruciate ligament. Am J Sports Med 34:787–792
31. Tsukada H, Ishibashi Y, Tsuda E et al (2008) Anatomical analysis of the anterior cruciate ligament femoral and tibial footprints. J Orthop Sci 13:122–129
32. Tuman JM, Diduch DR, Rubino LJ et al (2007) Predictors for hamstring graft diameter in anterior cruciate ligament reconstruction. Am J Sports Med 35:1945–1949
33. Vidal AF, Brucker PU, Fu FH (2005) Anatomic double-bundle anterior cruciate ligament reconstruction using tibialis anterior tendon allografts. Oper Tech Orthop 15:140–145
34. Yagi M, Wong EK, Kanamori A et al (2002) Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. Am J Sports Med 30(5):660–666
35. Zantop T, Wellmann M, Fu FH et al (2008) Tunnel positioning of anteromedial and posterolateral bundles in anatomic anterior cruciate ligament reconstruction: anatomic and radiographic findings. Am J Sports Med 36:65–72
36. Zelle BA, Brucker PU, Feng MT et al (2006) Anatomical double-bundle anterior cruciate ligament reconstruction. Sports Med 36:99–108