Clinical Paper

Sagittal Plane Imaging Parameters for Computer-Assisted Fluoroscopic Anterior Cruciate Ligament Reconstruction

Tiburtius V.S. Klos, M.D., Scott A. Banks, Ph.D., Raymond J.E. Habets, M.Sc., M.T.D., Frank F. Cook, M.D.

Department of Orthopaedics and Traumatology, Catharina Hospital (T.V.S.K., R.J.E.H.), and Section of Medical Electrical Engineering, Eindhoven University of Technology (R.J.E.H.), Eindhoven, The Netherlands, and Orthopaedic Research Laboratory, Good Samaritan Medical Center, West Palm Beach, Florida, USA (T.V.S.K., S.A.B., F.F.C.).

ABSTRACT Reproducible graft placement in anterior cruciate ligament (ACL) reconstructions is considered to be a critical factor affecting the successful clinical outcome of the procedure. Many current ACL instrument systems rely on intra-articular landmarks to guide the ACL tunnel placement. However, most of these instrument systems use mobile soft tissues as landmarks. We hypothesize that consistently identifiable radiographic contour landmarks can be established that can be used to improve the reproducibility of graft tunnel placement in fluoroscopically and computer-assisted ACL reconstructions. For the tibia, magnetic resonance imaging (MRI) scans showed the average ACL attachment site to be projected at 46% on a line extending from the anterior to the posterior cortices. Intraoperative fluoroscopic images were checked for the reproducibility of this line and its clinical use. For the femur, lateral radiographs demonstrated a consistent relationship between the intercondylar roof line (Blumensaat's line) and the nearly circular profile of the posterior and inferior contour of the lateral femoral condyle. The middle of this circular profile is consistently projected on Blumensaat's line at 66% of its anterior-to-posterior direction. Intraoperative images were used, which showed the aiming drill at the point of entering the lateral femoral condyle. Instead of determining the femoral attachment site relative to Blumensaat's line, we can thus determine its position relative to the center of the circle. Based on intraoperative x-rays, the proposed femoral ACL attachment site can be projected on a line parallel with the Blumensaat's line from the circle center in the posterior direction. Our results indicate that there are consistently identifiable radiographic features on the tibia and femur contours that can be used for fluoroscopic and computer-assisted guidance of ACL graft placement. Comp Aid Surg 5:28–34 (2000).

Key words: **ACL reconstruction, graft placement, fluoroscopy, computer-assisted knee reconstruction**

INTRODUCTION

One of the most critical factors for successful clinical outcome of anterior cruciate ligament (ACL) reconstruction is proper intra-articular positioning of the graft. There is general agreement that long-

Received July 23, 1999; accepted December 16, 1999

Address correspondence/reprint requests to: Tiburtius V.S. Klos MD, Department of Orthopaedics & Traumatology, Catharina Hospital, Michelangelolaan 2, 5623 EJ Eindhoven, The Netherlands. Telephone: 31-40-239-7182; Fax: 31-40-245-8979; E-mail: 100276.1726@compuserve.com

term results are significantly influenced by correct tunnel placement.[4,6,9,10,22,23,37,40,41,43,47] In order to achieve reproducible results, numerous conventional techniques have been developed using guiding instrumentation for graft placement. This guiding instrumentation can be placed according to soft tissue or bony landmarks.

In the context of a computer-assisted surgery (CAS) system, where simple non-contact sensing and guidance are desirable, identification of bony landmarks is more easily accomplished using common radiographic methods (i.e., fluoroscopy). The use of fluoroscopy has long been recommended to provide additional intraoperative feedback to the surgeon.[15] Currently, Blumensaat's line[16,26] on the femur and the tibial spine[13] are used as landmarks in fluoroscopically assisted graft placement. The goal of this study was to identify bony structures that are easily visualized using fluoroscopy and can be used for establishing a consistent measurement reference for computer-assisted ACL graft placement.

Other CAS systems for ACL reconstruction have focused on isometry and graft elongation[41] or on impingement-free placement.[21] Our approach is purely geometric, not functional, with the goal of finding anatomic and radiographic parameters for graft placement which facilitate improved surgical repeatability.

METHODS

MRI Evaluation of Tibial Site

To define a landmark for the tibial attachment site of the ACL, the tibial localization technique, as proposed by Stäubli and Rauschning,[45] was used in 64 sagittal MRI studies with intact anterior cruciate ligaments. In sagittal MRI images of an extended knee, the ACL appears as a straight bundle parallel to the intercondylar roof. In these images, the center of the ACL was identified and its location was determined relative to two anterior-to-posterior lines (Fig. 1). The most anterior point on the tibial cortex (1) and the most posterior point on the posterior cortex (4) defined the first line. The most anterior superior point on the tibial cortex (2) and the most posterior superior point on the tibial cortex (3) defined the second line. We compared the variation in attachment-site location for both lines using an F-Test.

Surgical Validation of Tibial Site

After determining which line exhibited greater consistency in identifying the ACL location, we compared tibial tunnel positions to that line for 25 cases

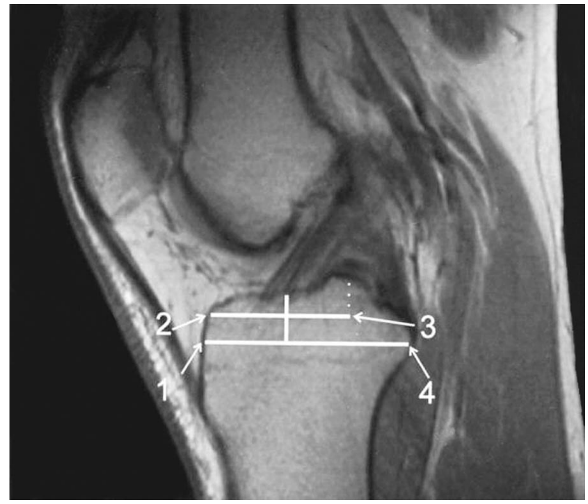

Fig. 1. MRI scan showing the center of the ACL and its position relative to two lines on the tibia: (I) the line between the most anterior point on the anterior cortex (1) and the most posterior point on the posterior cortex (4), and (II) the line between the most anterior point on the tibial joint surface (2) and the most posterior point on the tibial surface (3).

of ACL reconstruction using a standard arthroscopic method described by Morgan et al.[31] In this method, the tibia drill hole is defined to be a constant distance in front of the posterior cruciate ligament (PCL). The validity of the proposed ACL location, based on the bony tibial anatomy, was determined in comparison to the location of graft placement using Morgan's method.

Radiographic Evaluation of Femoral Site

We used a modification of Harner's method[16] on 48 trans-epicondylar lateral radiographs to determine the location of the ACL attachment and identify bony features suitable for fluoroscopic guidance. Harner's technique uses the radiographic projection of the intercondylar notch, Blumensaat's line, to define the femoral measurement system. Unfortunately, precisely identifying the anterior and posterior terminals of Blumensaat's line is much more difficult in fluoroscopic images than in higher-resolution radiographs. Instead, we chose to fit a circular template to the easily visualized distal and posterior contours of the lateral femoral condyle. True lateral radiographs, which shows the condyles overlapping, is used for defining the position of the middle of the circle in relation to Blumensaat's line. By demonstrating a consistent relationship between the condylar circle and Blumensaat's line, Harner's measurement approach can be easily extended for use with fluoroscopic images (Fig. 2).

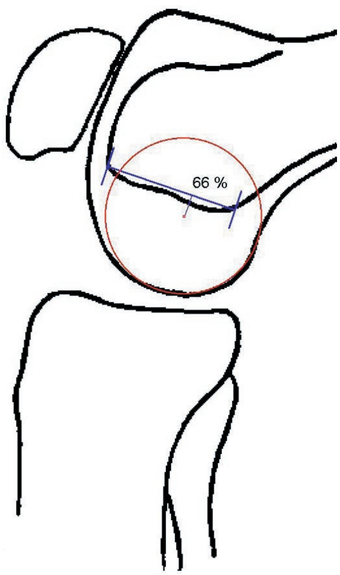

Fig. 2. The Blumensaat's line is projected in relation to a circle formed by the continuation of the posterior and inferior contours of the lateral femoral condyle. The middle of this circle is at a mean position of 66% (standard deviation of 5%) in an anterior-to-posterior direction.

Surgical Validation of Femoral Site

Having determined the relationship between the condylar circle and Blumensaat's line, the applicability of the condylar circle was assessed on intraoperative fluoroscopic images of 50 cases of ACL reconstruction. In Morgan's method, the femoral drill hole is related to the over-the-top position (Fig. 3). The femoral attachment site was projected onto a line through the circle center and parallel to Blumensaat's line. The distance from the attachment site to this line and the distance from the circle's center in the direction of Blumensaat's line were recorded (both as a percentage of the circle diameter: anterior 0%, posterior 100%).

Surgical Implementation

Having established radiographic parameters for graft placement, we developed a system which uses fluoroscopic images to interactively check proposed graft placement preoperatively and the position of guiding instrumentation intraoperatively.[24] The preoperative planning is performed on a hyperextension sagittal X-ray image. The surgeon uses the information from the computer monitor to guide graft placement. If necessary, iterative adjustments to graft placement can be conducted, e.g., in case of severe hyperextension or extremely steep notch angles. Since the coronal position (medial-lateral) of the tibia drill hole is much more easily controlled by arthroscopic feedback than the sagittal position, the current system only assists in sagittal plane alignment.[24]

RESULTS

The center of tibial attachment site in the MRI series was found at 46% ± 3% with respect to the line defined by points 1 and 4, and at 52% ± 5% with respect to the line defined by the points 2 and 3 (Fig. 4). The standard deviation for the first line is smaller, indicating that the ACL insertion site can be estimated more reliably relative to a line connecting the A/P tibial cortices (points 1 and 4). The 3% standard deviation in attachment site corresponds to approximately 2 mm. The center of the condylar circle was determined at an average position of 66% ± 5% along the Blumensaat's line in an anterior-to-posterior direction (Fig. 5). The 5% standard deviation is roughly equivalent to a distance of 2 mm.

Since we are using fluoroscopic images in surgery, we also checked these lines on intraoperative fluoroscopic images, in which we used a drill guide as a reference point instead of the ACL insertion. The placement was measured by two observers in 25 cases. Tibial placement was located at 47% ± 2% and 47% ± 3% on the anterior-to-posterior line (points 1–4). From the series of 50 surgical cases, the mean femoral insertion site was located at 61% ± 5% on the anterior-to-posterior cross-section of the circle (Table 1).

DISCUSSION

The goal of this study was to define radiographic landmarks for guidance and improved repeatability

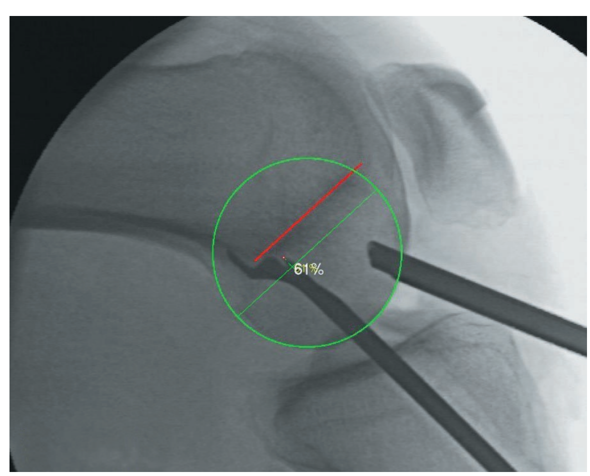

Fig. 3. The mean position of femoral graft insertion, using an over-the-top aiming device, is 0.61 on the cross-section of the circle.

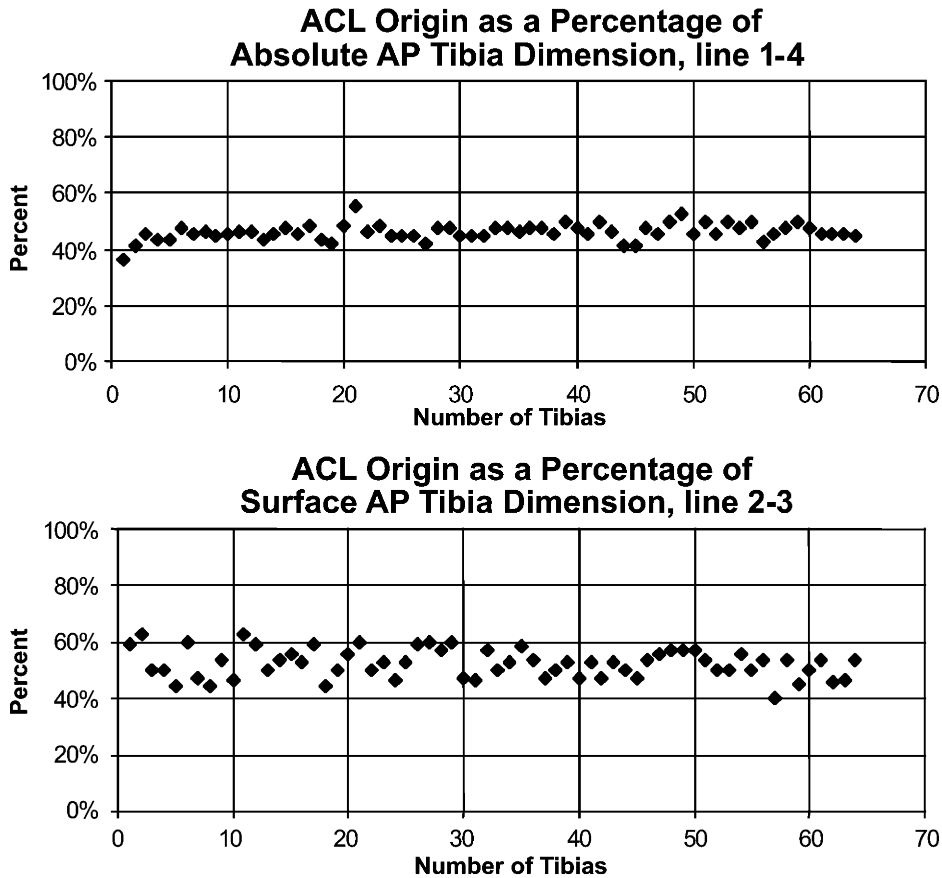

Fig. 4. Variations in the relationship between the center of the tibial attachment for 64 knees with intact ACLs with the line between points 2 and 3 and the line between points 1 and 4 (Fig. 1).

of graft placement during computer-assisted ACL reconstruction. It is not possible to determine "optimal" graft placement criteria from this study. Different positions have been advocated for graft placement,[1,5,11,14,17,18,27,34,35,44] both on the tibial[8,13,19,20,29,32,33,35,39,45,48] and femoral tun-

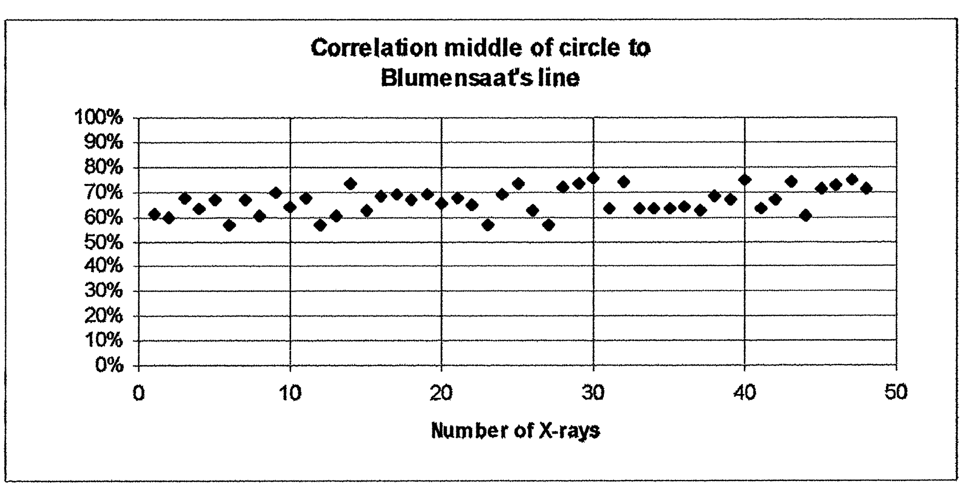

Fig. 5. Data obtained from 48 lateral radiographs of the femur. A circle was superimposed on each radiograph, with the middle of the circle projected just beneath the intercondylar roof. The position of the middle of the circle was then compared to the Blumensaat's line, extending from anterior to posterior (Fig. 2).

Table 1. Relation Between Position in Circle and Femoral Placement in 50 Intraoperative Images (See Fig. 3).

		Observer 1	Observer 2	Observer 3	Observer 4
Circle	Mean	61%	61%	61%	61%
Std. Dev.		4%	5%	5%	4%

nel[1,11,14,18] sites. We tried to establish a reference frame for performing intraoperative measurements, and succeeded in acquiring useful tools for CAS-type ACL reconstructions. The origin of the ACL is on the non-articular posterior aspect of the medial surface of the lateral femoral condyle. As the ligament extends distally, it is composed of three bundles — the antero-medial, intermediate, and postero-lateral bundles.[30,46] During reconstruction, only parts of the original anatomy can be restored.

Tibia: Over the years, different guidelines have been provided in the literature,[12,19,32,33,45,48] but the central or intermediate position has generally been advocated for the tibial attachment site of the ACL graft. Morgan et al.[31] proposed an insertion site 3–7 mm in front of the PCL. Goble[12,13] used the front slope of the tibial spine as a radiographic aiming point for the tibial guide pin. Stäubli and Rauschning[45] used Magnetic Resonance Arthrography (MRA) to measure the tibial insertion site of the ACL in 35 patients with intact ACL's. Based on their findings, the authors recommend placing the center of the tibial tunnel at 44% from the anterior tibial margin along the anterior-posterior line. We used the method of Stäubli and others on a large number of normal MRI exams and found a slightly different position for the tibial insertion site. The difference in absolute values between 44% and 46% is less than 1 mm (front-to-back distance of tibia head being $<$5 cm[49]).

Femur: On the femoral site, guidelines provided in the literature are even more divergent. There is discussion about optimal position,[1,5,7,11,17,26,27] about the method of measuring femoral placement,[1,16] and about the effect of graft placement on stability.[3,22] In this study we set our femoral parameter to one position, which is acceptable for us.

Fluoroscopy: Halbrecht and Levy[15] recommend the routine intraoperative use of a fluoroscopic image intensifier during surgery to obtain a lateral view of the knee. Radiation exposure is limited,[8,25] with only one imaging direction (i.e., lateral). In order to find easily identifiable radiographic parameters, we searched for a contour-related method. In many studies, the joint line is used[2,3,16,26] to measure the position of the tibial canal on postoperative X-rays in the sagittal view. From our study, it can be concluded that there is a considerable variation in the joint-line measurement technique. The contour-related measurement we proposed could be used for locating the tibial drill-hole in intraoperative radiographs. Further research is necessary to determine if this measurement technique is suitable for postoperative radiographs. In most studies, areas related to either Blumensaat's line itself[16,23,26] or to both Blumensaat's line and contours[3,7] are used. It would be ideal to have a method to score drill-hole placement in ACL reconstruction. Amis et al.[2] used a circle to reference dimensions in knees. Cazanave and Laboureau[5] and Mattheck et al.[28] used the middle point of the circle to guide placement. By analyzing intraoperative fluoroscopy in ACL reconstruction, an area for placement was found in relation to the condylar circle. However, it must be remembered that this area depends on the instrumentation and technique. Other types of reconstruction techniques and/or instrumentation will lead to other areas. From our study, we cannot determine which area is superior for drill-hole placement. There are no methods available to score the knee kinematics and the quality of their restoration. Without such methods it is difficult to compare surgical techniques. Current scoring systems are focusing on clinical data, which are often investigator-dependent. The use of additional objective data like KT-2000 test results is reported to have considerable interobserver variance.[38] Our study demonstrates that there are consistently identifiable radiographic features on both the tibia and femur that can be used to establish a measurement reference for guiding placement of ACL grafts. These features can be related to tunnel positions obtained by our current reconstruction technique using a PCL-oriented tibia drill-hole placement and a femoral guide referring to the "over the top" position. It also offers a set of parameters which could be useful for optimizing reproducibility of graft placement. We assume a constant radiographic anatomy of the knee joint in the lateral projection. Individual adjustments are possible, and should be planned with the help of preoperative hyper-extension lateral radiographs. We now routinely use a CAS system which identifies these radiographic landmarks as a measurement reference. In our system, we developed an interactive measurement method for computer guidance by using the video images from the image intensifier. The computer generates overlays on the digital video image, displaying the virtual and proposed graft positions, before actual drilling is executed. This approach has allowed us to significantly reduce the variability of ACL graft locations.[24] The surgeon makes the final decision on acceptance of this position and performs the final drilling of the holes for graft placement.

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