Avoiding Complications and Technical Variability During Arthroscopically Assisted Transtibial ACL Reconstructions by Using a C-Arm With Image Intensifier

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Background: Surgical reconstruction of the anterior cruciate ligament (ACL) can be complicated by incorrect and variable tunnel placement, graft tunnel mismatch, cortical breaches, and inadequate fixation due to screw divergence. This is the first report describing the use of a C-arm with image intensifier employed for the sole purpose of eliminating those complications during transtibial ACL reconstruction.

Purpose: To determine if the use of a C-arm with image intensifier during arthroscopically assisted transtibial ACL reconstruction (IIAA-TACLR) eliminated common complications associated with bone–patellar tendon–bone ACL reconstruction, including screw divergence, cortical breaches, graft-tunnel mismatch, and improper positioning of the femoral and tibial tunnels.

Study Design: Case series; Level of evidence, 4.

Methods: A total of 110 consecutive patients (112 reconstructed knees) underwent identical IIAA-TACLR using a bone–patellar tendon–bone autograft performed by a single surgeon. Intra- and postoperative radiographic images and operative reports were evaluated for each patient looking for evidence of cortical breeching and screw divergence. Precision of femoral tunnel placement was evaluated using a sector map modified from Bernard et al. Graft recession distance and tibial α angles were recorded.

Results: There were no femoral or tibial cortical breaches noted intraoperatively or on postoperative images. There were no instances of loss of fixation screw major thread engagement. There were no instances of graft-tunnel mismatch. The positions of the femoral tunnels were accurate and precise, falling into the desired sector of our location map (sector 1). Tibial α angles and graft recession distances varied widely.

Conclusion: The use of the C-arm with image intensifier enabled accurate and precise tunnel placement and completely eliminated cortical breach, graft-tunnel mismatch, and screw divergence during IIAA-TACLR by allowing incremental adjustment of the tibial tunnel and knee flexion angle. Incremental adjustment was essential to accomplish this. Importantly, a C-arm with image intensifier can be used with any ACL reconstruction that incorporates tunnels in the technique, with the expectation of increase in accuracy and precision and the elimination of common complications.

Clinical Relevance: The use of an image intensifier during transtibial ACL reconstruction will substantially reduce the common complications associated with the procedure and improve both accuracy and precision of tibial and femoral tunnel placement. Use of an image intensifier unit is generalizable to an individual surgeon's preferences for graft choices and drilling techniques and will be especially valuable when the intercondylar architecture is altered from injury, time, or prior surgery.

Keywords: transtibial anterior cruciate ligament reconstruction; image intensifier; complications

Arthroscopically assisted transtibial anterior cruciate ligament (ACL) reconstruction (TACLR) has been used for years to successfully stabilize ACL-insufficient knees.[16] However, failure rates as high as 15% have been reported and attributed to departures from technique that include incorrect and variable tunnel placement, screw divergence, graft-tunnel mismatch, graft impingement, cortical breaches, and inadequate fixation.[‡] Despite numerous studies evaluating ACL anatomy, 14% to 43% of tunnels

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‡References 3-5, 12, 17, 23-26, 40, 45, 48.

have been reported to be inaccurately placed.[14] Other reports suggest that transtibial approaches have contributed to imperfect positioning of the femoral tunnel because of the limitations inherent in passing the guide wire through the tibial tunnel.[1,22,27,28,38] Inadequate fixation strength, as a result of divergence of interference screws, has been reported in up to 84% of surgeries performed.[15,31] The incidence of graft-tunnel mismatch is reported to be as high as 56%.[36,42] Solutions for graft-tunnel mismatch, including twisting of the graft, folding of the plug onto the graft, and tying the distal plug to a fixation post, may all compromise the outcome. While the use of an anteromedial portal has allowed for flexibility when placing the guide pin for the femoral tunnel, divergence, mismatch, and breaches remain a problem.[6,7,21,32]

Modifying the technique of Goble,[19] Halbrecht and Levy[20] reported on the use of an image intensifier while reconstructing the ACL when using a transtibial approach. The technique was described to eliminate the potential for breach of the posterior femoral cortex, to avoid anterior placement and failure of the tibial tunnel, and to reduce the possibility of divergence of the femoral fixation screw. Unexpectedly, the technique allowed for advancement (recession) of the bone-tendon construct and screw placement within the femoral condyle and all but eliminated graft-tunnel mismatch. It was noted during the development of the assisted procedure that the femoral tunnel could be precisely and reliably placed by minimally altering the tibial drill (and tunnel) and knee flexion angle, thereby avoiding inadvertent distal or posterior placement of the tunnel within the femur.

One author (I.M.L.) has for the past 20 years consistently used the C-arm with image intensifier for tunnel and screw placement during arthroscopic ACL reconstruction. It was the goal of this study to determine whether the image intensifier and arthroscopically assisted transtibial ACL reconstruction (IIAA-TACLR) reduced the number of common complications associated with bone–patellar tendon–bone (B-PT-B) ACL reconstruction. We also considered the following questions: Did the occurrence of screw divergence and cortical breaches of the femur and tibia decrease when using IIAA-TACLR? Was the femoral tunnel accurately and precisely located using IIAA-TACLR? Could graft recession be reliably used as a solution for graft tunnel mismatch?

It was our hypothesis that the use of the image intensifier during transtibial ACL reconstruction significantly decreased the occurrence of screw divergence and cortical breaches of the tibia and femur when compared with established norms. Furthermore, we hypothesized that the use of IIAA-TACLR allowed for accurate and precise tunnel placement. Finally, we hypothesized that the use of IIAA-TACLR permitted reliable recession of the proximal bone plug along with accurate screw placement, thereby eliminating graft-tunnel mismatch.

MATERIALS AND METHODS

The institutional review board approved this study, and informed consent was waived. From April 2011 to April 2013, a total of 110 consecutive patients (112 reconstructed knees), determined by physical examination and magnetic resonance imaging (MRI) to have a torn ACL, underwent identical IIAA-TACLR using a B-PT-B autograft performed by 1 surgeon (I.M.L.) using a technique modified from Halbrecht and Levy.[20]

Surgical Technique

Patients were positioned supine on the operating table, the uninvolved leg placed in a well-padded support, and the injured leg firmly held by the leg holder (Figure 1). The uninvolved leg was flexed and abducted at the hip and flexed at the knee to position that leg away from the lateral imaging beam. The leg section of the operating table was flexed to 110°. The C-arm was then positioned around the affected leg, and a true lateral view of the knee was obtained. The C-arm and patient were draped with the affected leg draped free to allow that leg to move through a full range of motion.

With the surgeon sitting in front of the patient, a standard arthroscopy was then performed. The cruciate injury was confirmed, and all meniscal and cartilage injuries were managed. A limited intercondylar notchplasty was performed. After completing the notchplasty, a B-PT-B graft was harvested and prepared for placement. With the aid of the image intensifier, a drill guide was positioned on the anterior tibia. The drill guide's aiming tip was passed through a 5-mm anterior inferior medial portal and placed at the junction of the middle and posterior thirds of the anterior cruciate footprint. This position was equidistant from the anterior edges of the medial and lateral tibial spines (when seen on the lateral fluoroscopic projection) and on a sagittal line that was immediately adjacent to the lateral border of the posterior cruciate ligament (when seen arthroscopically). The guide's drill sleeve was then placed on a subperiosteal window created just medial to the tibial tubercle and anterior to the insertion of the tendons of the pes anserinus. Importantly, using the image intensifier, the angle and position of the drill guide and the knee flexion angle were adjusted, in every case, so that the drill sleeve pointed at the junction of the middle and posterior thirds of the ACL tibial footprint and simultaneously to where the femoral tunnel was to be located. A guide wire was then passed through the tibia, and the angle of the guide wire was evaluated to insure that the femoral tunnel that would result from it was properly located, would not breach the posterior femoral cortex, and would allow for a shuttle pin passing through the tunnel to emerge from the anterior cortex of the femur. With the aid of the image intensifier, minor adjustments of the guide wire and knee flexion angles allowed for precise positioning. The tibial tunnel was subsequently reamed. A guide wire was then passed through the tibial

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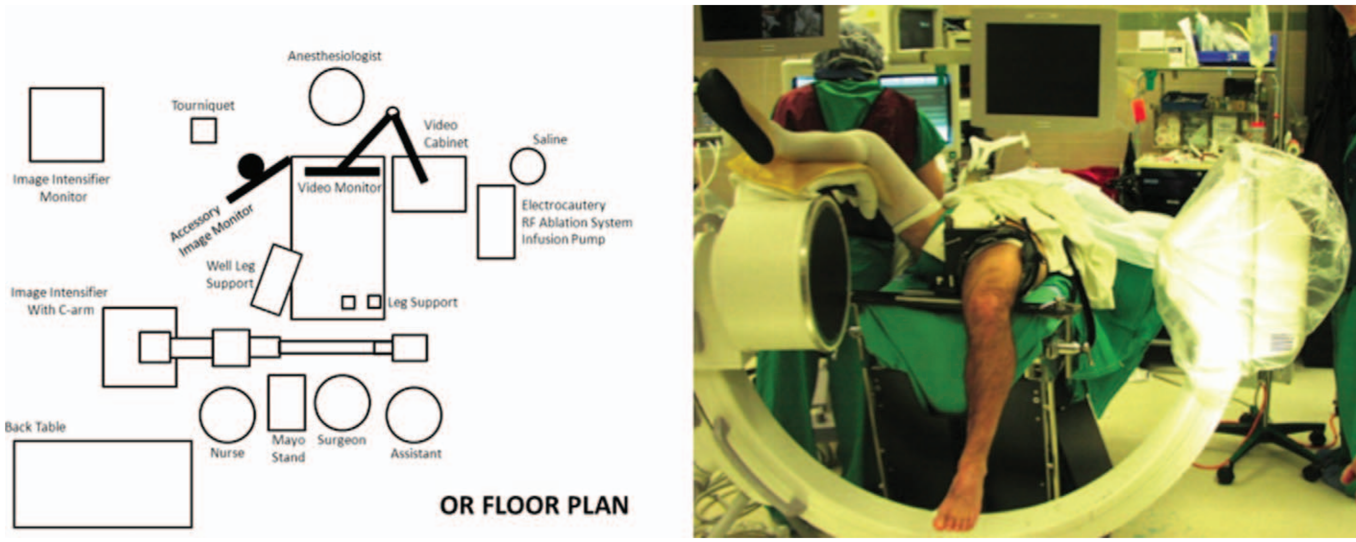

Figure 1. Operative setup. OR, operating room.

tunnel and placed on the femoral attachment site, the "desired site." For all 112 knees, the desired site was located 6 mm distal to the posterior limit of the intercondylar notch in the 11 or 1 o'clock position. Medial-lateral positioning was accomplished using the arthroscope. Proximal-distal and anterior-posterior positioning was determined with the image intensifier. The angle of penetration of the guide wire into the femur was visualized with the image intensifier and adjusted by changing the knee flexion angle. Minor alterations of the guide wire insured that the tunnel reamer avoided the posterior cortex of the femur, the tunnel was long enough to seat the entire graft, and the tunnel was of sufficient angle that the shuttle drill (used to pass the graft sutures) could penetrate the anterior femoral cortex. When the drill position and angle were finally accepted, the guide wire was advanced (Figure 2). In every case, the guide wire was incrementally adjusted to achieve these requirements. The femoral tunnel was then reamed. The length of the previously harvested and prepared graft was used to determine the femoral tunnel depth.

The tunnel positions were selected based on anatomical studies.[18] The guide wire placed in the tibia was positioned toward the posterior third of the footprint because the angled reamer created an elliptical tunnel hole in the tibial plateau with the majority of the opening in front of the guide pin. The femoral position selected was based on the work of Girgis et al[18] and supported by more recent reports.[9,38]

When the tunnels were completed, the graft was passed. The femoral screw was then placed with its progress tracked simultaneously with the arthroscope and image intensifier. After the femoral screw was seated, the graft was cycled and tensioned and the tibial screw was then placed while visualized directly and with the aid of the image intensifier. After both screws were placed, the leg was rotated and viewed on the image intensifier to confirm that the screws were fully engaged.

Each patient had a final permanent image at the time of surgery. At 1 week after surgery, anterior-posterior (AP) and lateral radiographs were taken to confirm the position of the graft and screws.

Figure 2. Advancement of femoral tunnel guide wire with aid of image intensifier.

Patient Selection

Patients for the study were identified using the annual case logs of the senior surgeon (I.M.L.). A patient was included if they had undergone an image intensifier and arthroscopically

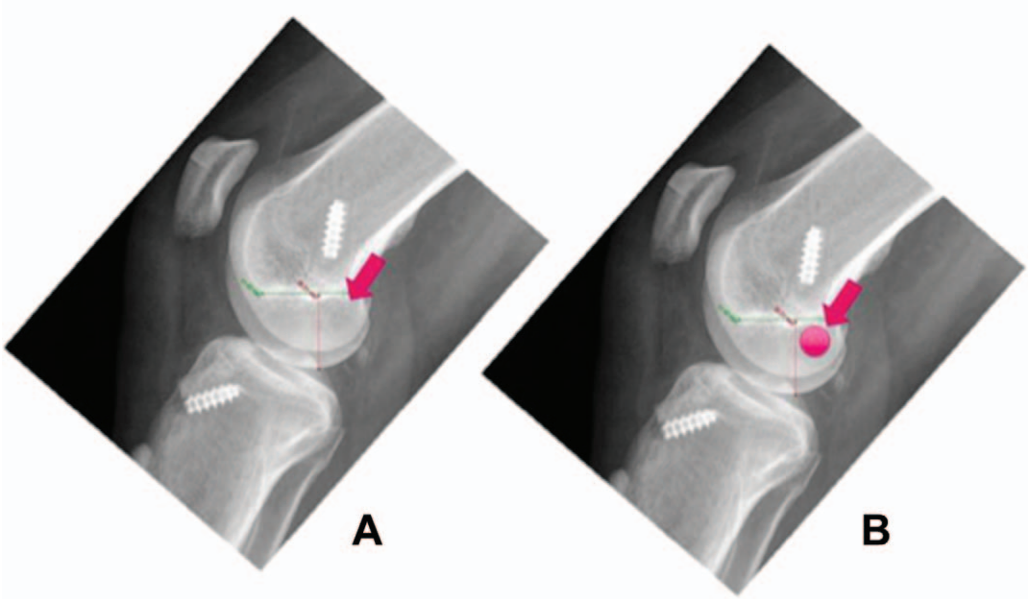

Figure 3. Femoral tunnel opening identification. (A) Arrow indicates radiographic lucency representing femoral tunnel opening. (B) Circle represents femoral tunnel opening.

assisted isolated primary ACL reconstruction using B-PT-B autograft. Only those patients whose radiographic imaging was available on digital film were included in the study group. Patients with tears of the ACL who had meniscal tears or cartilage injuries were included. Patients were excluded from the study if they had undergone previous ACL surgery on the same knee or a primary reconstruction with an allograft. Operative reports were reviewed to be sure that the identical procedure had been performed. A total of 110 consecutive patients (112 knees) were included, all of whom underwent IIAA-TACLR with a B-PT-B autograft using the technique modified by Halbrecht and Levy.[20]

Data Collected

Patient demographics, including age, sex, comorbid conditions, height, and weight, were collected from patients' medical records. Intraoperative data, including graft sizes, concurrent injuries, and procedures, and intraoperative complications were recorded.

Each patient had a final permanent image at the time of surgery. At 1 week after surgery, AP and lateral radiographs were taken to confirm the position of the graft and fixation screws. The 1-week radiographs were all performed on a Phillips Digital Diagnost (Eindhoven, Netherlands) x-ray machine using the Release 214 software package.

These images were reviewed, and any evidence of cortical breaching of the femur or tibia or screw divergence was recorded. A breach was defined as any compromise of the cortical integrity of the tibia or femur resulting from pin placement, tunnel reaming, or screw fixation. Screw divergence was described as the loss of major thread engagement with the bone plug noted on either the AP or lateral radiograph. Loss of engagement of the conically shaped screw tip was not considered divergent. The femoral tunnel opening was visualized on all radiographs (Figure 3, A and B). Femoral tunnel opening location was recorded using a 6-sector map modified from Bernard et al[9] and was constructed as follows (Figure 4, A-G): Using the digital software, a perpendicular line was drawn from the Blumensaat line and extended posteriorly to the farthest point on the lateral femoral condyle (Figure 4A). The Blumensaat line was drawn and measured (Figure 4B). Two lines, equal in length to the perpendicular line, were extended from the anterior and posterior limits of the line drawn along the Blumensaat line (Figure 4C). A line was then drawn parallel to the Blumensaat line passing through the distal ends of the previously drawn perpendiculars (Figure 4D). Lines were drawn parallel to the perpendiculars dividing the Blumensaat line into thirds (Figure 4E). The perpendicular lines were measured and bisected, and a line was drawn parallel to the Blumensaat line, passing through the bisector (Figure 4F). The final result was a 6-sector map (Figure 4G). We determined that our "desired site," located 6 mm distal to the posterior limit of the intercondylar notch and in the 11 or 1 o'clock position, was located fully within sector 1. By our definition, any tunnel that was more than 20% (2 mm) out of the sector was considered to be in the next sector. This was selected to accommodate for 10-mm tunnels that were drilled in knees with Blumensaat lines that were <27 mm.

Using the digital software, tibial tunnel angles were determined on lateral radiographs by measuring the angle "α" created by the intersection of a line drawn tangential to the lateral tibial plateau and a line running parallel to the anterior wall of the tibial tunnel (Figure 5A). Again using the digital software, tibial and femoral screw-graft angles were measured on AP and lateral radiographs, as previously described by Rodin and Levy,[39] and then categorized into 1 of 4 groups: 0°-4.99°, 5°-9.99°, 10°-14.99°, and $\geq 15^\circ$.

The distance from the middle of the femoral tunnel opening to the distal end of the proximal bone plug was measured

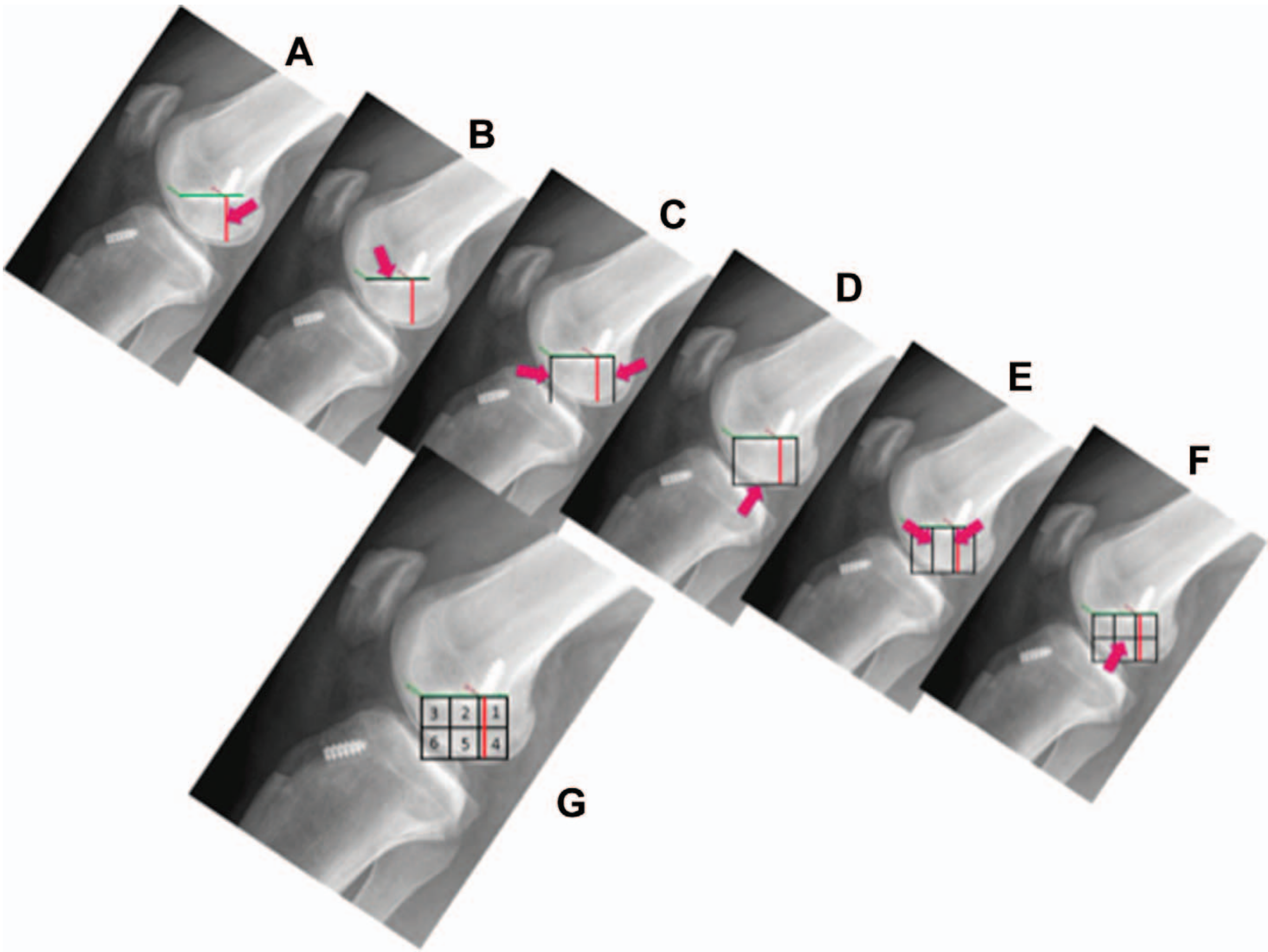

Figure 4. Unique 6-sector mapping creation process.

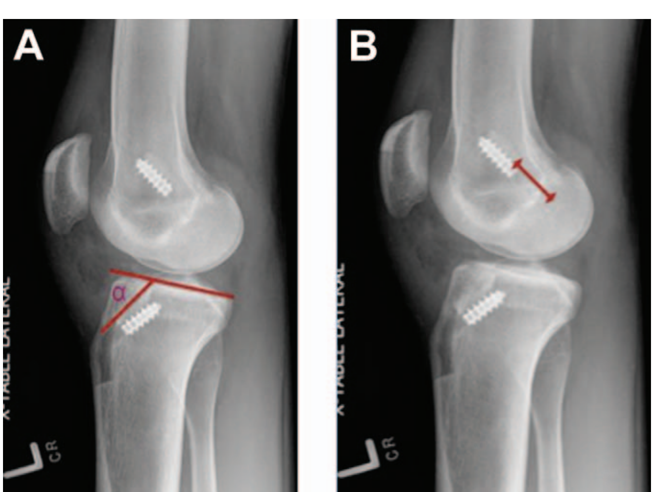

Figure 5. Postoperative radiographic measurements. (A) Tibial α angle and (B) recession distance.

using the digital software and defined as the "recession distance" (Figure 5B).

Statistical Analysis

Descriptive statistics were calculated to examine demographic variables in the cohort. Means and standard deviations (SDs) were reported for continuous variables, such as age and angle measurements.

RESULTS

One hundred twenty-five consecutive ACL reconstructions performed by the senior author (I.M.L.) from April 2011 to April 2013 were identified. Thirteen were excluded because of the use of allograft tendon or revision surgery. The remaining 112 consecutive knees in 110 consecutive patients underwent image intensifier and arthroscopically assisted primary ACL reconstructions with B-PT-B autografts as described. All 112 operative reports were reviewed to ensure that the identical procedure had been performed. Eighty-three patients suffered concurrent injuries, including chondral injuries, meniscus tears, or combinations of these. Seventy patients underwent concurrent procedures.

The average age of the patient at surgery was 23 years (range, 14-44 years; SD, 6.7 years) and included 87 male patients and 25 female patients. Patients were an average of 174 cm tall (range, 152-193 cm; SD, 11 cm), weighed 83 kg (range, 49.9-142.8 kg; SD, 19 kg), and had an average body mass index of 27.0 kg/m^2 (range, 18.8-42.6 kg/m^2; SD, 5.0 kg/m^2).

The average overall graft length was 50 mm (range, 37-70 mm; SD, 6.0 mm) (Figure 6A). The tendon graft width was 10 mm, and the graft bone plugs were 20 mm long, 10 mm wide, and cylindrical in shape in all cases. The average femoral recession distance was 8.16 mm (range, 0.57-26.34 mm; SD, 5.17 mm) (Figure 6B). There were no instances of graft-tunnel mismatch.

The average length of the Blumensaat line in our patient population was 30.12 mm (range, 23.93-39.32 mm; SD, 3.067 mm) (Figure 7). Following the construction of individual 6-sector maps on the postoperative radiographs, all of the femoral tunnel openings were found to be located in sector 1, with no tunnel 2 mm (20%) beyond the sector. There was 100% accuracy and 100% precision. There were no femoral or tibial cortical breaches noted intraoperatively. This was confirmed on postoperative imaging.

With regard to screw divergence, when evaluated on postoperative AP and lateral radiographs, screw and grafts were found to exist in 3 conditions. In the first condition, the screw and graft were parallel or nearly parallel in both projections. In the second condition, the screw and graft were parallel or nearly parallel in one projection and not parallel in the other projection. Importantly, in this second condition, all the major screw threads remained fully engaged. In a third condition, “divergent,” there is a loss of the screw’s major thread engagement with the bone plug in either the AP or the lateral radiographs; that is, there were no instances of divergence. The average femoral screw-graft angles were 4.45° and 3.62° in the AP and lateral projections, respectively. The average tibial screw-graft angles were 3.71° and 2.26° in the AP and lateral projections, respectively. The majority of the screw-graft angles fell within the 0°-4.99° group (Table 1).

The average tibial α angle for our surgical population was 59.59° (range, 39.7°-76.8°; SD, 6.84°) (Figure 8). None of the relationships between patient height and graft length, patient height and Blumensaat length, or patient height and importantly, tibial α angle, accounted for more than 22% predictability (Figure 9, A-C).

DISCUSSION

Anterior cruciate ligament reconstruction is a common surgical procedure done to restore the stability of an ACL-deficient knee.[16] It is a safe procedure with a low complication rate; more than 100,000 reconstructions are performed annually in the United States.[11] However, the failure rate has been reported as high as 15% and is secondary to cortical breaches, graft-tunnel mismatch, graft impingement, divergent screw placement, and incorrect and variable tunnel location.[§]

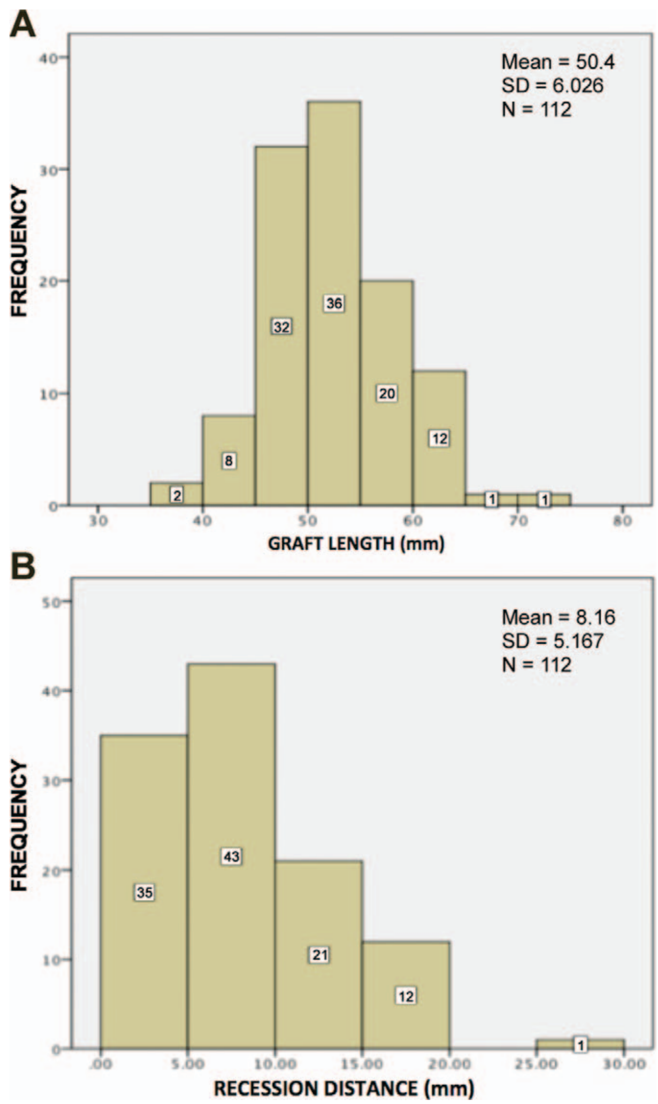

Figure 6. (A) Distribution of graft lengths in study population. (B) Distribution of recession distances in the study population.

In 1988, Goble[19] introduced the use of the image intensifier to assist with ACL reconstruction. Despite variances in patient morphology, he was able to reproduce the appropriate landmarks on the tibia and femur, allowing for the isometric placement of both tibial and femoral tunnels. Halbrecht and Levy[20] described the use of the IIAA-TACLR in an effort to decrease the rate of complications from cortical breaches, screw divergence, and improper tunnel positioning.

In the present study, we evaluated the ability of IIAA-TACLR to (1) enable accurate and reliable placement of the femoral tunnel, (2) optimize interference screw placement,

[§]References 3-5, 12, 17, 23-26, 40, 45, 48.

TABLE 1
Femoral and Tibial Screw-Graft Angles[a]

	AP Radiograph (n = 112)	Lateral Radiograph (n = 112)
Femoral screw-graft angle, deg		
0-4.99	80 (72)	89 (79)
5-9.99	19 (17)	19 (17)
10-14.99	7 (6)	4 (4)
≥15	6 (5)	0 (0)
Tibial screw-graft angle, deg		
0-4.99	87 (78)	102 (91)
5-9.99	19 (17)	9 (8)
10-14.99	5 (4)	1 (1)
≥15	1 (1)	0 (0)

[a]Values are expressed as n (%). AP, anterior-posterior.

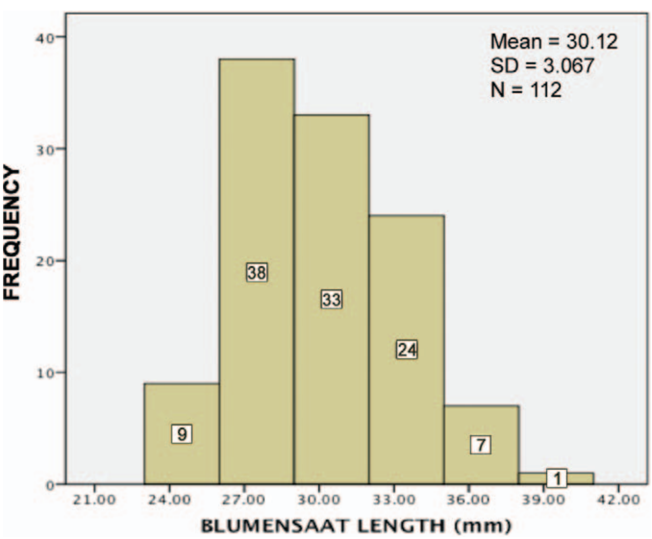

Figure 7. Distribution of length of the Blumensaat line in the study population.

(3) avoid iatrogenic femoral and tibial tunnel breaches, and (4) prevent graft-tunnel mismatch by recessing the graft within the femoral condyle.

Deviation from anatomic tunnel placement occurs in up to 43% of ACL reconstructions.[14] When looking at failed primary ACL reconstructions, studies have attributed 88% to 96% of failures to malpositioned tunnels.[34,43] Dargel et al[14] noted 43% of 50 patients had femoral tunnels that were malpositioned when using a transtibial drilling technique for primary ACL reconstruction. In patients undergoing primary ACL reconstruction using an anteromedial portal drilling technique, 14% of 50 patients were noted to have femoral tunnels malpositioned.

Tunnel placement, using IIAA-TACLR, was both accurate and precise with all of our femoral tunnel openings falling within sector 1, our “desired site.” With radiographic landmarks used to locate and validate the same position, it is reasonable to expect a high degree of accuracy and precision. In this study, the 6-sector map was elected to

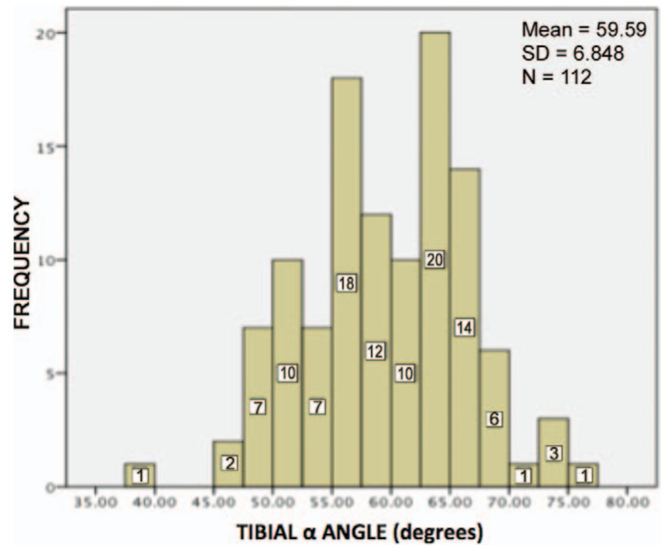

Figure 8. Distribution of tibial α angle in the study population.

evaluate tunnel position instead of the map designed by Bernard et al[9] because the 10-mm femoral tunnel openings were larger than a single sector in Bernard’s design, thereby making classification more challenging. With a rigorous definition of tunnel location within a sector (less than 2 mm outside the sector), we felt that the use of the 6-sector map was valid.

Although it was not the purpose of this study to validate a particular site, some words regarding “ideal location” are necessary. Anatomical studies by Girgis et al[18] and others suggest that the anatomical footprint falls within our sector 1.[2,27,38] Ahn et al[2] and others[27,38] have commented that the transtibial approach is more likely to lead to femoral tunnels that are further from the anatomical center. However, Ahn et al[2] and Heming et al[22] also point out that the transtibial technique can be successful with meticulous positioning of the tibial tunnel. We concur with that opinion. The use of fixed angle drill guides in cadaveric studies evaluating the transtibial approach result in suboptimal tunnel locations. However, in this study, by adjusting both the guide and knee flexion angle, the desired site was achieved in all cases with anatomical tunnels and without “vertical” grafts.

Four clinical studies evaluating the graft-screw relationship identified screw divergence in up to 61%.[10,31,37,41] Lemos et al[31] found as high as 36% screw divergence when using a single-incision endoscopic technique for ACL reconstruction. Using criteria similar to Lemos et al,[31] Brodie et al[10] found 8% to have significant divergence using a transtibial arthroscopic technique. Schroeder,[41] using a different definition of divergence, reported as much as 57% divergence with their anteromedial portal technique and 8% divergence with their transtibial technique. Pandey et al[37] reported an average femoral screw divergence in the sagittal plane of 13.38° using the anteromedial portal technique versus 7.20° using a patellar tendon portal technique through the donor defect, with 82.9% in the anteromedial

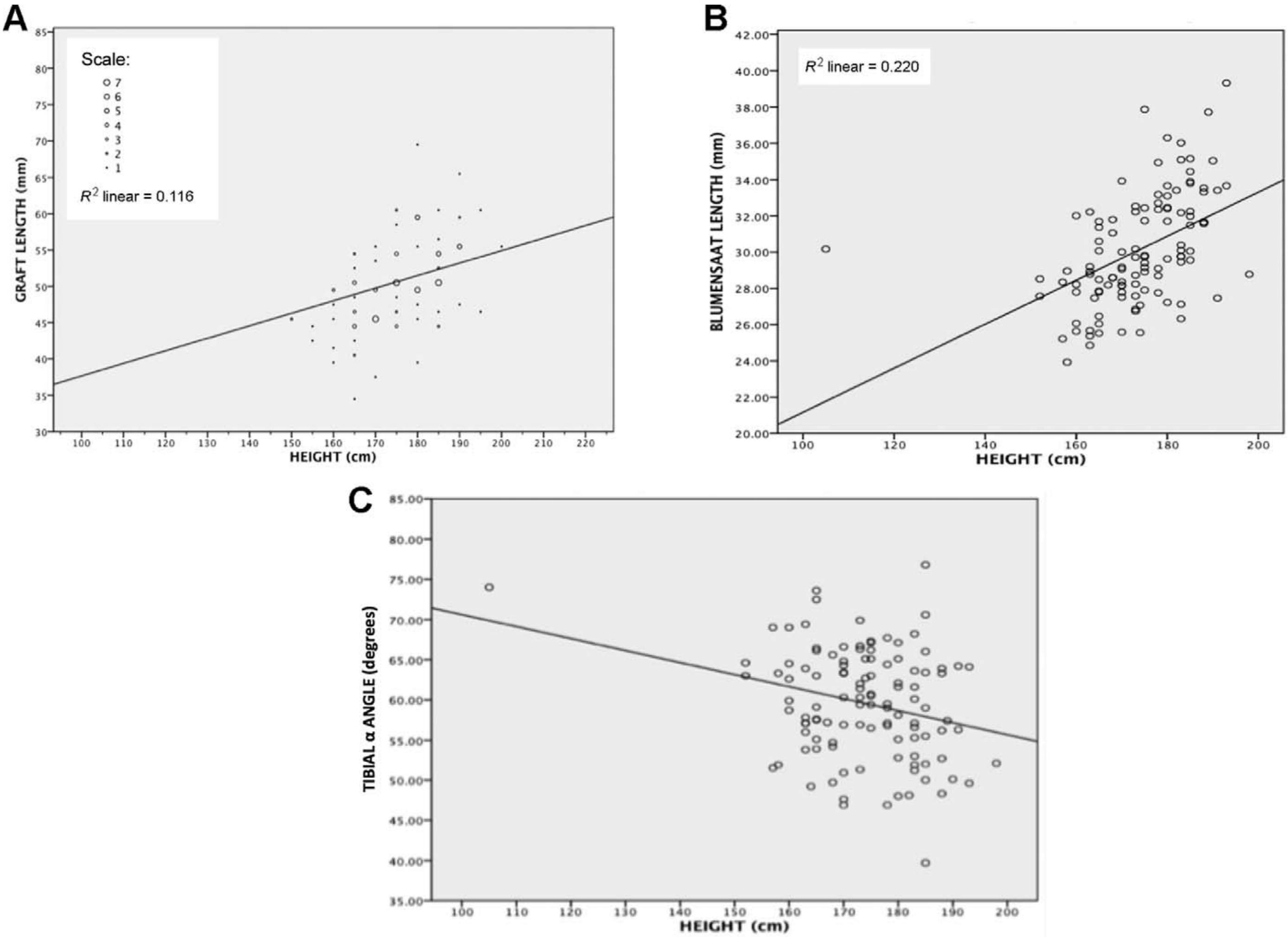

Figure 9. Correlation of (A) graft length, (B) Blumensaat length, and (C) tibial α angle with patient height in the study population.

portal group and 17.1% in the transpatellar technique group considered moderately or severely divergent.

Using IIAA-TACLR, all interference screws were completely engaged; that is, all our grafts maintained contact with the major threads of the fixation screw in both radiographic projections. Even recessed plugs were consistently fixed with no incidence of loss of thread engagement in either projection (screw divergence).

Graft-tunnel mismatch has been cited in the literature as a complication of poor preoperative planning or simply an inevitable outcome in a certain percentage of patients. Techniques have been developed to compensate for intraoperative graft-tunnel mismatching, but its true incidence is generally unknown. Shaffer et al[42] found 26% graft-tunnel mismatch in their series of 34 consecutive B-PT-B autograft ACL reconstructions. With IIAA-TACLR, bone plugs were reliably recessed, completely eliminating graft-tunnel mismatch.

There is a preponderance of literature stating that cortical breaching must be avoided. However, there are only 7 case reports in the literature, and as such, there are no specific values assigned to the incidence of this complication.[8,33,35,44,46,47] We were unable to compare our results to the literature given the infrequency of reports of the complication in the literature. IIAA-TACLR completely eliminated cortical breaches of both the tibia and femur.

In all areas of concern, IIAA-TACLR performed better than the reported literature. Intraoperative use of the image intensifier allowed the surgeon to subtly alter knee flexion angle as well make incremental changes in the tibial drill angle. We showed that small changes in tibial drill angle are essential for the success of the procedure (Figure 8). These small drill angle changes result in a tibial tunnel angle that not only gives the surgeon access to the desired femoral drill site but also allows for precise angulation of the femoral tunnel. A favorable femoral tunnel angle enabled easier interference screw placement and insured that the tunnel angle was steep enough to allow a shuttle pin to breach the anterior femoral cortex. Variations in portal height as well as differences of tibial architecture make achieving these goals using a drill guide with its angle fixed or predetermined difficult if not impossible. While the limitations resulting from passing a guide wire through the tibial tunnel are not encountered when using an anterior-medial portal, the potential problems of tunnel misplacement, graft-tunnel mismatch, screw divergence, and even cortical breach still exist.

For this study, we selected only patients that underwent primary IIAA-TACLR with B-PT-B autograft in an effort to evaluate an identical procedure. The authors believe that a transtibial approach is the most rigorous test for use of image guidance but should not, in practice, be used exclusively for TACLR. While only B-PT-B grafts were used in this study, fixation of any graft can be monitored with use of the image intensifier.

Even though the use of the image intensifier permits a superior level of consistency in terms of tunnel placement and the avoidance of intraoperative complications, concerns about the radiation exposure to the surgeon and patient have been raised. Recent studies have demonstrated that the radiation dose delivered to patients and a surgeon during IIAA-TACLR is safe when using either a miniature or standard C-arm with image intensifier unit.[13,29,30] In our study, use of the image intensifier did not increase operating time. The setup was simple, did not require adjustment, and the image times were always less than 1 minute. To save operative and image exposure time, the lateral image was used exclusively. Medial-lateral positioning of both the tibial and femoral drill positions was readily accomplished by direct arthroscopic visualization.

Using single-plane radiographs for analysis of the position of the femoral tunnel opening on the lateral wall is appropriate. While the intercondylar notch is 3-dimensional, the medial wall of the lateral femoral condyle is adequately described using planar terminology. Computed tomography imaging simplifies targeting but ultimately uses planar analysis to determine femoral tunnel position.[2,27,38] This is readily accomplished with planar radiography that is orthogonal and is based on a true lateral image. In addition, planar radiography is routine and exposes the patient to far less radiation.

Finally, all studies benefit from controls. While having such a cohort would have added validity to the study, we were concerned that we would create a group that, at best, had an equivalent complication rate but was more likely to have a higher one. Believing this would have been unethical and difficult to get approval from an institutional review board, we chose to use the literature as our control.

It must be emphasized that this study was not done to validate a position of the femoral tunnel (ie, the “desired site”) or to validate the results of IIAA-TACLR. The single goal of the study was to show that the use of the image intensifier could substantially reduce technical variability and the complications that can result from that variability. To accomplish this, the tibial drill angle needed to be adjusted in every case, and this could only be accomplished with the aid of the image intensifier. Proper placement of the femoral guide wire, femoral tunnel drilling, and recessed screw placement could only be accomplished with incremental changes in knee flexion angle, and that could only be verified with the aid of an image intensifier.

In summary, the use of IIAA-TACLR is a safe and reliable method for reconstruction of the ACL-insufficient knee. The technique minimizes the risk of poorly positioned tunnels, cortical breaches, graft-tunnel mismatch, and screw divergence. While the study was limited to use in TACLR with B-PT-B autografts, the technique is readily applied to all other ACL reconstruction methods by ensuring accuracy of tunnel placement, graft position, and fixation of the graft. The use of a C-arm with image intensifier during ACL reconstruction has the potential for altering the outcomes of 15,000 patients per year. It is our opinion that all ACL reconstructions can benefit from the use of the C-arm with image intensifier, especially when the injuries are chronic or during revision surgery when the intercondylar anatomy may be altered.

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