

# The Relationship Between Anterior Cruciate Ligament Reconstruction Tibial Tunnel Location and the Anterior Aspect of the Posterior Cruciate Ligament Insertion

David A. McGuire, M.D., Stephen D. Hendricks, and Heather M. Sanders

---

**Summary:** A retrospective study of arthroscopic anterior cruciate ligament reconstruction in 20 patients was conducted. These patients underwent computed tomography (CT) scans on the involved knee postoperatively to determine sagittal placement of the proximal end of the tibial tunnel (TTp) based on a distance from a specific anatomic reference known as the over-the-back (OTB) ridge. The distance from the posterior aspect of the TTp to the OTB ridge, defined as the backset, was measured from the CT scans. The mean backset was 6.2 mm. The anterior to posterior (AP) tibial plateau diameter was measured from the CT and by plain view radiograph. The mean AP diameter by CT scan was 55.1 mm and the mean AP diameter by radiograph was 55.4 mm. A Pearson correlation coefficient of  $r = .633$  comparing backset versus AP diameter suggests a moderately significant positive relationship. For the AP diameter comparing measurement method, CT versus radiograph,  $r = .985$ , representing a highly significant positive relationship, confirming AP diameter sizing accuracy by inexpensive radiography versus CT scan. A proposed backset model based on these data uses three fixed distances, derived by ratio, within a 2-mm range. This model is defined by 5-, 6-, and 7-mm backset intervals for <50 mm, 50 to 60 mm, and >60 mm AP diameters respectively, and is currently under prospective clinical investigation. **Key Words:** Anterior cruciate ligament—Reconstruction—Tibial tunnel placement.

---

Advances in arthroscopy have focused on the design and implementation of equipment needed to perform various surgical techniques. Consequently, methods of reconstructing the anterior cruciate ligament (ACL) have progressed notably, resulting in this procedure being commonly performed on an outpatient basis.

In 1963, Jones described a technique using the central one third of the patellar tendon.<sup>1,2</sup> Although this technique is not the only means of treatment for ACL

injuries, it has become increasingly popular because the bone-tendon-bone (BTB) graft provides several fixation options, robust graft incorporation, and a mechanically sufficient substitute.<sup>3</sup>

Distal femoral tunnel (FTd) placement, described by Sidles et al. in 1988,<sup>4</sup> referenced bony anatomy in the intercondylar notch posteriorly. Prior positioning techniques, illustrated by Fuss,<sup>5</sup> resulted in FTd positions on the lateral femoral condyle medial aspect that varied considerably in both directions of the sagittal plane. ACL reconstruction failures, before the adoption of bony anatomy references, were generally attributed to inappropriate FTd placement. Recent FTd guides developed to reference bony anatomy have reduced variation in FTd placement, producing concentric uni-tunnel axes by drilling the femoral tunnel through the tibial tunnel.<sup>6,7</sup> This subsequent reduction in femoral tunnel variation has directed recent attention to the

---

*Private Practice.*

*Supported in part by research funding from Depuy Inc., Warsaw, Indiana, U.S.A.*

*Address correspondence and reprint requests to David A. McGuire, M.D., Knee and Arthroscopic Surgery, 4048 Laurel St, Suite 202, Anchorage, AK 99508, U.S.A.*

*© 1997 by the Arthroscopy Association of North America  
0749-8063/97/1304-1558\$3.00/0*

precise location of the proximal end of the tibial tunnel (TTp). Both the accuracy of the FTd guides and the effect tibial tunnel placement has on femoral tunnels drilled with this protocol dictate control requirements more stringent than currently considered acceptable.

If the TTp is placed too anterior or posterior, range of motion (ROM) deficit, knee instability, or graft failure may result. Several authors have proposed anterior placement of the TTp<sup>8-11</sup> superimposing the anterior margin of the TTp on the anterior margin of the footprint of the ACL. This technique has met with various difficulties including intercondylar roof impingement, extension deficit, problems during knee flexion, graft thinning, and graft failure.<sup>12-19</sup> Posterior placement of the TTp also has pitfalls as a causal relationship with knee laxity has been reported.<sup>9,11,20,21</sup>

Current TTp positioning techniques relying on soft tissue landmarks are inherently imprecise. A common method to locate the center of the TTp in the sagittal plane uses the tangent line drawn from the anterior central rim of the lateral meniscus. This method is an approximation and can be unreliable if the meniscus is deranged, has been resected, or is discoid.

Some authors have sought to identify a relationship between TTp location and AP diameter expressed by a ratio.<sup>22-27</sup> Another method has been described placing the center of the TTp at a fixed 7-mm distance from the anterior aspect of the posterior cruciate ligament (PCL) measured sagittally at the tibial plateau, regardless of patient size.<sup>28</sup>

The purpose of the present study was to identify the optimal tibial tunnel location for ACL reconstruction. The criteria for the study were to compare placement of the TTp established by fixed distance or by ratio, and to propose a reproducible and accurate technique to preoperatively determine an appropriate position for the TTp. We began exploring a TTp placement model by proposing the following hypotheses: (1) TTp location is related to constant bony anatomy, (2) the distance between the tibial tunnel and a bony anatomy reference is related to patient size, and (3) measurements taken from plain film radiographs corrected for magnification are an accurate indicator of patient size.

## MATERIALS AND METHODS

Twenty patients (9 women, 11 men) were selected retrospectively for this study. Their surgeries occurred between May 8, 1992, and April 4, 1995 and were performed by the first author (D.A.M.). The

**TABLE 1.** Patient Demographics

	Mean	SD	Range
Age (y)	40.3	8.9	17-52
Surgical latency* (y)	2.4	5.5	0.02-20.98
Follow-up (d)	207.1	58.3	145-379

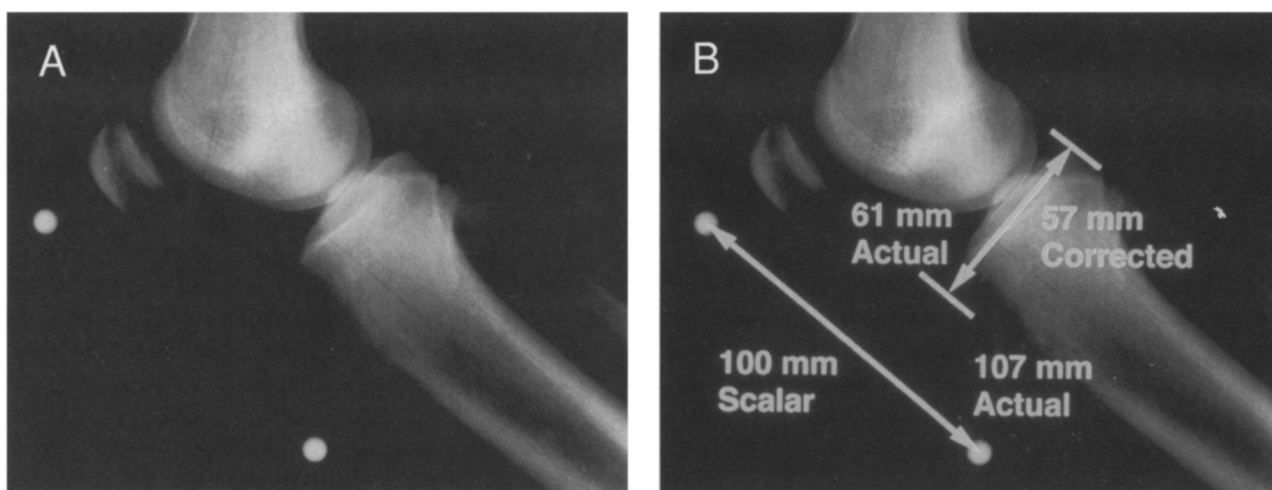
\* Time from injury or onset of symptoms to surgery.

demographic data are listed in Table 1. All patients have undergone arthroscopic primary reconstruction of the ACL. A single-incision technique was used with BTB graft with radiograph-translucent bioabsorbable interference screw fixation supplied at the distal and proximal points of graft attachment. The TTp was placed using a guide pin positioned axially (medial/lateral) in the center of the ACL tibial stump and sagittally (anterior/posterior) on a tangent line drawn from the anterior central rim of the lateral meniscus. Femoral tunnels were drilled through the tibial tunnels and were placed with an endoscopic aimer, high in the notch, with a resultant posterior cortical margin of 1 to 2 mm.

The criterion used for patient selection was a 30-lb side-to-side difference of  $\leq 2$  mm as tested with a MedMetric KT2000 instrumented arthrometer (MedMetrics, San Diego, CA) 6 months postoperatively by the second author (S.D.H.). Both allogenic ( $n = 10$ ) and autogenous ( $n = 10$ ) BTB grafts were used. Every patient had a lateral-view radiograph with a 100-mm scalar used to determine and correct for x-ray magnification. The method for using this scalar is illustrated in Fig 1.

All patients in this study underwent postoperative computed tomography (CT) scans on their involved knee to determine the placement of the TTp based on a distance measurement to a specific bone anatomic reference known as the over-the-back (OTB) ridge located just anterosuperior to the tibial insertion of the PCL. CT scans were taken in 1-mm intervals. Measurements from these scans were made on a Sun Sparc computer (Sun, Mountainview, CA) with Siemens 3D software (Siemens, Iselin, NJ) from the digital data acquired directly from the CT scan equipment. The most proximal CT slice at the tibial plateau was used to measure the distance from the posterior aspect of the TTp to the OTB ridge. We have called this space the backset, illustrated in its relationship with the tibial tunnel and the PCL in Fig 2.

Backset measurements were taken from the CT slice where the posterior aspect of the tibial tunnel breached the tibial plateau as shown in the representative CT



**FIG 1.** (A) This example of a lateral view radiograph taken from patients in this study is referenced for magnification by a scalar that can be used to correctly measure magnified dimensions. The distance between the center of the two small circles (scalar endpoints), shown anterior to the tibia, is 100 mm. (B) This radiograph is approximately 7% larger than the patient. The formula for converting the actual dimension of the tibial plateau to a corrected one is as follows:

$$\frac{\text{scalar dimension}}{\text{actual scalar measurement}} = \frac{100 \text{ mm}}{107 \text{ mm}} = \frac{? \text{ mm}}{61 \text{ mm}} \frac{\text{corrected AP measurement}}{\text{actual AP measurement}}$$

$$100 \times 61 \div 107 = 57 \text{ mm} = \text{corrected AP measurement.}$$

slice in Fig 3. Measurements of AP tibial plateau diameters were taken from the lateral view radiographs and the CT slice located distally to the corresponding slice used for backset evaluations.

To address our first hypothesis, proximal tibial tunnel location is related to constant boney anatomy, the Backset versus anterior to posterior (AP) diameter Pearson correlation coefficient was calculated to evaluate the relationship between these bivariate data. The second hypothesis, the distance between the tibial tunnel and a boney anatomy reference is related to patient size, was assessed by measuring the location of the center of the tibial tunnels by two methods; first, as a discrete distance from the anterior edge of the tibia, and second, as a percentage of the AP diameter. Subsequently, these data were compared by method and gender to evaluate differences and similarities. The third hypothesis, measurements taken from plain film radiographs corrected for magnification are an accurate indicator of patient size, was assessed comparing the CT scan AP diameter versus radiograph AP diameter data using the Pearson correlation coefficient.

We also made measurements described by authors presenting tunnel location data as ratios to compare our results with theirs. All clinical data statistical analysis were performed with SPSS 6.1.1v software (SPSS, Chicago, IL).

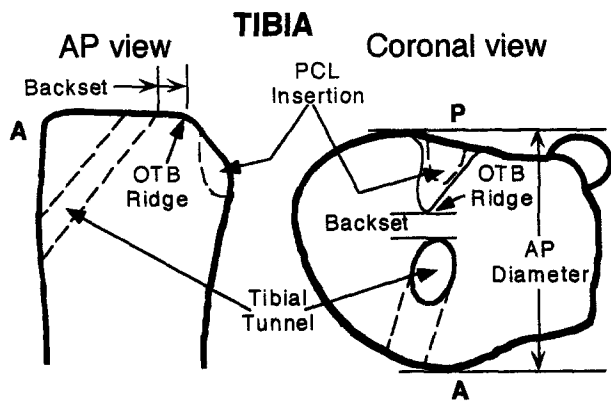
## RESULTS

The mean backset was 6.2 mm (range, 4.0 to 7.3 mm). The mean AP diameter by CT scan was 55.1 mm (range, 47.3 to 64.0 mm), and the mean AP diameter by radiography was 55.4 mm (range, 49 to 64 mm). Graft type and individual measurements for backset and AP diameter by method are presented for comparison in Table 2. The calculated Pearson correlation coefficient for these two variables,  $r = .633$ , portrays a moderately significant relationship between them.

A comparison of CT AP sagittal diameter versus radiographic AP sagittal diameter,  $r = .985$ . An  $r$  value this close to 1 (the maximum) shows a highly significant relationship between the computer aided measurement (CT) and a manual measurement (radiography) confirming the dimensional accuracy of radiography when used with a scalar.

## DISCUSSION

Ideally, the optimal position of an ACL replacement graft should re-establish physiological laxity and normal knee mobility. These standards are assessed in the sagittal plane and deficiencies are associated with two related complications, ROM deficit and graft laxity.

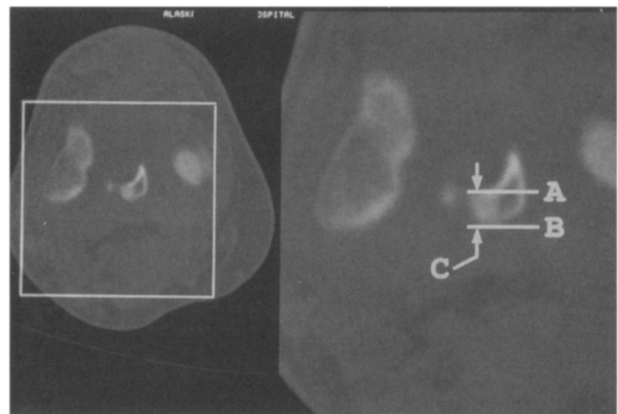


**FIG 2.** The tibia is shown with a tibial tunnel, PCL insertion, and the OTB ridge. Note that the anterior aspect of the PCL and OTB ridge are not the same point viewed coronally. The former is positioned anterior to the latter; therefore, comparisons of measurements made from these different references to the posterior aspect of the TTP cannot be made directly without considering by how much they differ from each other. The backset is measured from the posterior aspect of the tibial tunnel to the v-shaped ridge of the trough and not to the soft tissues of the PCL. The AP view is taken from the perspective of the tibia transected at the apex of the v-trough of the OTB ridge.

Extension deficit is the most commonly reported postoperative symptom, often occurring from impingement by the roof of the intercondylar notch on the ACL graft during knee extension.<sup>19</sup> This complication has been attributed to the center of the TTP positioned anterior to the center of the ACL tibial insertion, inadequate notchplasty, or both. In contrast, flexion deficit may occur from posterior TTP positions, which have a reported causal relationship with graft lengthening greater than 2.5 mm for ROM from 0° to 90°.<sup>17</sup> Excessive anterior or posterior sagittal TTP positions result in graft stretching when full ROM is achieved in knees with tunnel malposition induced ROM deficit.

**Anterior Tunnels**

In 1982, Clancy et al.<sup>8</sup> suggested that the tibial tunnel be placed anteromedial, describing the position as “excentric” [sic] to the ACL attachment footprint. The reasoning for this choice relates to the resultant horizontal-as-possible graft orientation, theoretically restraining anterior tibial translation through more efficient biomechanical positioning. Hoogland and Hillen<sup>10</sup> in 1984 concluded, from their cadaveric study, that a position of the tibial tunnel anterior to the normal insertion of the ACL was required to decrease the shortening of the ACL graft during knee flexion. As late as 1992, anterior positions of the tibial tunnel were advocated by O’Brien<sup>9</sup> based on a “zones of isometricity” concept whereby the most isometric placement



**FIG 3.** This CT scan slice is viewed distally (anterior is at the top and posterior is at the bottom). The area shown in the square on the left is magnified on the right. The letter A indicates the posterior aspect of the tibial tunnel and the letter B the OTB ridge. The letter C shows the backset distance defined by the association between A and B.

of the graft could be achieved when pivot points identified by an isometer were centered on each end of the graft, specifically originating with those points on the anterior aspect of the tibial insertion of the ACL.<sup>11</sup>

In 1984, the association of ROM extension deficit and anterior tibial tunnel placement was identified by

**TABLE 2. Backset Versus AP Tibial Plateau Diameter**

Patient	Graft	AP Tibial Plateau Diameter (mm)		
		Backset (CT) mm	CT	Radiograph
1	Allo	7.0	52.8	52
2	Auto	4.9	53.8	53
3	Auto	6.3	59.2	60
4	Allo	4.9	48.0	49
5	Allo	7.0	56.0	55
6	Auto	5.2	48.1	49
7	Allo	4.0	49.9	50
8	Auto	5.0	53.6	53
9	Allo	7.3	54.8	54
10	Auto	7.7	57.1	58
11	Auto	7.3	59.3	60
12	Allo	6.1	47.3	49
13	Allo	7.2	56.8	56
14	Allo	6.0	50.1	51
15	Auto	5.1	56.8	58
16	Auto	6.0	64.0	64
17	Auto	6.0	57.1	58
18	Allo	6.2	58.3	59
19	Allo	6.3	58.7	59
20	Auto	6.7	59.3	60
Mean		6.2	55.1	55.4
SD		0.86	4.53	4.47
Range		4.0-7.3	47.3-64.0	49.0-64.0

Noyes et al.<sup>29</sup> and Kieffer et al.<sup>12</sup> Noyes identified the cause as impingement between the roof of the intercondylar notch and the anterior fibers of the ACL graft whereas Kieffer merely stated that anterior tunnel placement could cause problems with knee flexion. Initially, impingement problems were associated with inadequate roofplasties as they were suggested as solutions for patients with anteriorly placed tibial tunnels and extension deficits.<sup>13,14</sup>

In 1992, Howell and Clark<sup>15</sup> noted anterior tibial tunnel placement "consistently produced graft impingement and flexion contractures." They suggested placing the TTP center at 22 to 28 mm (37% to 47%) from the anterior edge of the tibia or 2 to 3 mm posterior to the center of the normal ACL insertion. This tunnel position avoided graft impingement and resulted in significantly better stability and knee extension. Our results for the distance of the TTP to the anterior edge of the tibia (mean, 23.0 mm) compare favorably with Howell and Clark's suggested location 22 to 28 mm. Our ratio mean of 41.5% and is within their ratio range (37% to 47%) corresponding to the proposed distance range.

Furthermore, Howell and Taylor believe that grafts in anterior tunnels are forced to elongate gradually rather than failing structurally because of the tendency of the reconstructed knee to achieve extension values similar to the contralateral knee.<sup>19</sup> In the MRI study of Howell et al., all of the graft fibers in the impinged (anterior tunnels) patient group as well as the unimpinged (central tunnels) patient group were anatomic and entirely within the pathway of the original ACL.<sup>13</sup> They accordingly noted that the cadaver findings by Hefzy et al.<sup>30</sup> supported their clinical observations that isometric tibial tunnel placement was achieved for both groups in their study even though the impinged group experienced significant extension deficit and the unimpinged group did not.

### Posterior Tunnels

In their cadaver study, Hefzy et al.<sup>31</sup> reported that isometer excursion profiles of  $\leq 2$  mm could be achieved for any fiber within the ACL tibial insertion stump by accordingly altering the corresponding femoral insertion site. In a cadaver study, Penner et al.<sup>21</sup> clearly showed that posterior tibial tunnel placements resulted in isometer excursion values significantly greater than the 5% to 6% ( $\approx 2.5$  mm) length changes the normal ACL undergoes with passive knee motion. We believe that an ACL graft installed in a TTP too posterior and tensioned properly will elongate in flexion if the patient achieves flexion values similar to

the contralateral knee. We have observed seemingly paradoxical evidence of instability postoperatively with grafts placed in this manner resulting in a negative Lachman and a positive (1+) pivot-shift test. Although the isometer may identify a posterior tibial tunnel placement when used with a fixed anatomic femoral tunnel location in cadaver studies, it is not designed to be used in this manner clinically. Therefore, relying on isometry to control the sagittal placement of the tibial tunnel clinically may not identify either anterior or posterior tibial tunnel placement resulting in roof impingement and flexion contracture,<sup>15</sup> or positive pivot-shift instability.

### Central Tunnels

In 1985, Odensten and Gillquist<sup>31</sup> recommended that the center of the TTP be placed in the center of the ACL tibial attachment. Locating the tunnel by this method is not without difficulty. Accurately determining the sagittal center of a debrided ACL stump arthroscopically is difficult without fluoroscopy. A standard method of overcoming this difficulty uses a tangent line drawn from the anterior central rim of the lateral meniscus providing a sagittal center for the tibial tunnel.<sup>34</sup> As stated previously, this method is an approximation and can be unreliable if the meniscus is deranged, has been resected, or is discoid.

Good et al.<sup>22</sup> advocated placing the TTP center at 33% of the AP diameter. Their study sought to validate the accuracy of a tibial drill guide comparing its use with free-hand drilling. Both methods were evaluated by expressing the tibial insertion site of the ACL as a percentile of the total midsagittal (AP) tibial diameter. Goble<sup>25</sup> described an ACL reconstruction technique with fluoroscopic control used to place the center of the tibial tunnel at  $\frac{1}{3}$  (33%) of the mid-sagittal diameter of the tibia.

In 1994, Khalfayan et al.<sup>24</sup> in their study of femoral and tibial tunnel position, reported TTP center placement within 20% to 40% of the AP diameter significantly improved knee stability and ROM compared with tunnels located outside this range. They used this criterion and a FTd center position of greater than 60% as a measured percent of posterior displacement along Blumensaat's line, to define group 1 patients. Group 2 patients included all others who didn't meet group 1 criteria. This wide suggested TTP range is probably due to the variation of their FTd position (mean, 71%; range, 35% to 95%).

In 1994, Jackson and Gasser<sup>26</sup> suggested placing the TTP center at 40% of the AP diameter resulting in BTB graft placement posterior and parallel to the inter-

condylar roof with the knee in full extension. The mean angle of the intercondylar roof has been reported by Mueller<sup>32</sup> to be 40° and by Good et al.<sup>33</sup> in cadaver knees to be 35°. Jackson and Gasser measured roof angles of 30° to 40° and had corresponding tibial tunnel angles, as measured to the tibial plateau, of 50° to 60°. Our method of determining tibial tunnel angle is to determine the knee angle when Blumensaat's line is parallel with the tibial plateau and drill the tunnel at that angle when the knee is flexed at that angle. Then, when the knee is extended, the graft, tunnel, and Blumensaat's line will be parallel.

In 1995 Howell and Barad<sup>27</sup> also identified the center of the tibial tunnel at 40% of the AP diameter in a radiographic study ( $n = 33$ ) on participants with no previous injury to their knees. Tunnel placement techniques that incorporate the use of ratios are either retrospective or require the use of fluoroscopy (C-arm) to target position. Retrospective studies suggest ratios that are based on patient outcome. The use of a C-arm certainly presents corrective capability while drilling the guide pin for the TTP; however, the very act of correcting the tunnel shows the degree of imprecision afforded this method, irrespective of the expense added to the procedure.

Another option would be to use magnetic resonance imaging (MRI) to determine the center of the ACL tibial attachment. In research by Staeubli et al.,<sup>19</sup> MRI scans performed on patients with meniscal pathology or anterior knee pain and intact cruciate ligaments ( $n = 35$ ) was used to measure the AP tibial diameter and locate the center of the ACL tibial attachment. These results were compared with cadaver knee measurements ( $n = 15$ ) obtained by dissection. The center of the tibial insertion of the ACL at the tibial plateau was 43% of the AP diameter for all knees combined. MRI is an accurate method for determining a proposed TTP center based on the center of the ACL tibial attachment, but the use of MRI preoperatively would add expense on top of that for the C-arm required to place the TTP center at a point defined by the MRI.

A relatively new method for locating the TTP center uses a fixed distance from the anterior aspect of the PCL.<sup>28</sup> This procedure uses an aimer that is placed against the PCL to produce a tunnel, the center of which is 7 mm from the PCL contact point on the aimer. This technique is based on cadaver sagittal MRI studies. However, any aimer used to abut the PCL may produce ambiguous results because PCL tissue may yield during the measurement. It is also unlikely that the center of all tibial tunnels should be exactly 7 mm anterior to the PCL regardless of patient size. Consider

the difference in posterior tibial tunnel wall position for an 10-mm versus a 12-mm tibial bone plug. If the center of each of the two tibial tunnels were positioned at the same point to correspond with each respective graft, the 12-mm tunnel would exist 1-mm further posterior than the 10-mm tunnel. Which tunnel would be correct using the 7-mm fixed distance? Long-term clinical studies of this technique have not been reported.

### Backset Model

Any system designed to exploit the relationship between backset and AP diameter must fulfill two criteria: (1) accurately measure AP diameter, and (2) place the posterior aspect of the TTP the distance selected based on the AP diameter regardless of tunnel angle. Our results with AP diameter by radiograph with a scalar compared with those by CT confirm that radiography is a viable means of measurement. The second criterion has several interrelated variables: accuracy by tunnel angle, accuracy by degree of tolerance, and range of functionality.

In the research by Staeubli et al.,<sup>23</sup> they noted a significant difference of the total AP diameter by gender, 53.7 mm for males versus 49.0 mm for females. In our study, mean AP diameter for males was 58.1 mm and for females was 51.3 mm, showing a significant difference of the total AP diameter by gender (t-test,  $P = .0002$ ). Additionally, the intergroup range for gender varies (female, 47.3 to 57.1 mm; male, 53.8 to 64.0 mm), displaying significant overlap intergroup as would be expected in a normal sample population. It is noteworthy that size and gender may affect tunnel position.

The AP diameter range for the present study was 47.3 to 64.0 mm. Using the mean ( $x = 55.1$  mm) and the standard deviation ( $SD = 4.51$ ), assuming a normally distributed population for the sample, we suggest the following prediction may be true:

67% of the population will fall within the range,

defined by the mean  $\pm 1$  SD ( $55.1 \pm 4.51$ ) =  
50.59 to 59.61 mm

90% of the population will fall within the range

defined by the mean  $\pm 2$  SD ( $55.1 \pm 2(4.51)$ ) =  
46.08 to 64.1 mm.

All of the participants in the present study fell within two standard deviations of the mean. Within a larger population it is reasonable to assume there will be patients with either larger or smaller AP diameters than those in our sample. We would propose three groups

based on AP diameter size using the mean  $\pm$  1 SD so that:

- Group 1 <50 mm small knees
- Group 2 50 = 60 mm average knees
- Group 3 >60 mm large knees.

Calculating a proposed backset for each group is not as straightforward as selecting group thresholds by AP diameter. Some clues to devising the second part of the backset model may be found in the coefficient of determination ( $r^2$ );  $r = .633$ , comparing backset versus AP diameter signifies a moderately significant relationship, whereas  $r^2 = .404$ , which is the ratio of explained variability to the total variability of the linear relationship between the backset and the sagittal tibial diameter. In other words, within this group of patients, we have accounted for about 40% of the total linear variation shown by these bivariate data. Because the AP diameters will serve as the backset selection reference, exploring sources of tunnel variation may reveal some unexplained variability. Of interest is the accuracy of the guide used to place the tunnels, the potential accuracy of any guide designed around the backset concept, and an acceptable backset range.

The accuracy of the guide used to place the TTP center in patients in this study is determined mostly by the tip of the guide placed in the tibial plateau. This point is positioned in the center of the ACL footprint and is the target the guide pin is drilled towards; however, the guide pin nearly always diverges in some direction because the tips of both the guide pin and the guide do not occupy the same point at the same time if the guide pin is drilled to breach and the guide remains secure. We have seen guides dislodge when the guide pin hits the tip, although this seems to happen less frequently than a simple divergence. The very fact that the guide dislodges probably indicates a guide that is not secure and when regularly used in this manner must contribute to placement inaccuracy. When deflected, the distance off-center is half the diameter of the widest point of the tip of the tibial guide added to half the diameter of the guide pin. For the various combinations of guides and guide pins available, this constitutes a 2- to 3-mm divergence error.

Another source of TTP placement variation is related to tibial tunnel angle. The sagittal length of the tibial tunnel opening is inversely related to its angle with the tibial plateau. Two tunnels drilled using the same center (guide pin position) at different angles can place the BTB graft at different backsets. An 11-mm tunnel drilled at 60° produces a 12.7-mm sagittal length opening. In contrast, a 30° tunnel produces a 22-mm open-

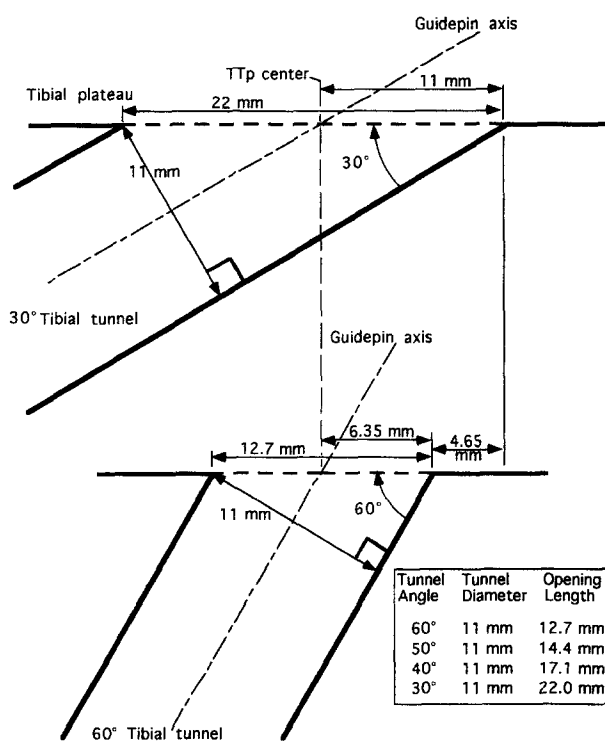


FIG 4. This illustration shows a 30° tunnel at the top and a 60° tunnel on the bottom comparing the posterior position of the tunnel wall for each of the tunnels:

- 30° tunnel: 22.0 mm  $\div$  2 = 11.0 mm posterior to guide pin
- 60° tunnel: 12.7 mm  $\div$  2 = 6.35 mm posterior to guide pin
- difference 4.65 mm.

ing. Consequently, each of these tunnels places the BTB graft fibers sagittally in positions 4.65-mm from each other (Fig 4). Whereas guidepin deflection may contribute some error, the angle of the tibial hole may be the most important factor. Within our own unpublished data we have seen tibial tunnel angles range from 42° to 76° (mean, 58°) produced from a guide pin system set at a constant 50°.

Sagittal BTB placement variations caused by tunnel angle would not ordinarily be identified by any current method of tunnel position assessment. This is because both of the currently accepted means identify tibial tunnel location referenced to the TTP center and not the posterior wall where the BTB graft fibers are commonly placed. Considering that these grafts are relatively flat, how these data apply to round grafts such as Achilles tendon, bone-quadriceps tendon, and four-bundle hamstring constructs poses an interesting question. Larger diameter soft tissue grafts may alter functional backset values. It would depend partially on the

femoral tunnel configuration. Conducting a similar study with these graft constructs is suggested to answer these questions.

If we had a tibial tunnel placement system that did not (1) rely on soft tissue references for guidepin placement, (2) guide tip/guidepin divergence error, and (3) tunnel angle backset error, tibial tunnel placement to a desired position would be more accurate. The reduction of these combined TTP placement variation errors would likely account for a greater percentage of explained variability of the total variability of the relationship between the backset and the sagittal tibial diameter.

To calculate a proposed backset for each AP diameter group, we began by selecting an acceptable backset range. Using the mean backset for the group,  $x = 6.2$  mm, we selected the closest integer value of 6.0 mm as the backset for group 2 (50 to 60 mm, average knees). Instrumentation based on the above described model is currently under prospective investigation by the authors. The prototype of this instrumentation has no guide tip that points the way to a guide pin, which it doesn't require because a coring reamer guided externally is used to produce the tunnel. Instead of a tip-pointed guide pin, the prototype's reference tab seats against the OTB ridge, locked into rigid position laying flat against the tibial plateau, which serves to control the tunnel angle. We believe a guide can be made to produce 0.5-mm tolerances if the three error-producing features of current tibial aimers were not incorporated into the design. This would allow for a backset range of 2 mm, the mean  $\pm 1$  mm. The backset values for group 1 (small knees) and group 3 (large knees) would be 5 mm ( $6 - 1$  mm) and 7 mm ( $6 + 1$  mm). This places the upper and lower backset dimensions approximately at the boundaries of the mean  $\pm 1$  SD ( $6.2 \pm 0.86 = 5.34$  to  $7.06$ ).

Based on this pilot study, we conclude that (1) tibial tunnel location is related to constant boney anatomy, (2) the backset and the size of the tibia have a moderately significant positive correlation, and (3) measurement of the tibial diameter by standard preoperative radiographs and by CT are highly statistically signifi-

cant. The accuracy of the standard preoperative radiographs permit them to be used to derive measurements to preselect the appropriate backset based on AP tibial plateau diameter. The significance of this research serves to define accurate placement of the tibial tunnel potentially reducing malpositioning and resultant failures either from loss of range of motion or abnormal laxity of the graft and proposes a method for positioning the tibial tunnel based on boney anatomy rather than on inherently imprecise soft tissue references.

Using the mean backset and the AP tibia diameter data we would propose the following model shown in Table 3 for tibial tunnel placement.

**Acknowledgment:** The authors thank Alaska Regional Hospital Radiology Department, Chugach Outpatient X-ray Services Inc., Alaska Surgery Center for their patient services.

## REFERENCES

1. Jones KG. Reconstruction of the anterior cruciate ligament. A technique using the central one-third of the patellar ligament. *J Bone Joint Surg Am* 1963;45:925-932.
2. Jones KG. Reconstruction of the anterior cruciate ligament. A technique using the central one-third of the patellar ligament. *J Bone Joint Surg Am* 1970;52:838-839.
3. Garth WP Jr. Current concepts regarding the anterior cruciate ligament. *Orthop Rev* 1992;21:565-575.
4. Sidles JA, Larson RV, Garbini JL, Downey DJ, Matsen FA. Ligament length relationships in the moving knee. *J Ortho Res* 1988;6:593-610.
5. Fuss FK. Optimal replacement of the cruciate ligament from the functional-anatomical point of view. *Acta Anat* 1991;140:260-268.
6. Marans HJ, Hendrix MR, Paterson RS. A new femoral drill guide for arthroscopically assisted anterior cruciate ligament replacement. *Arthroscopy* 1992;8:234-238.
7. McGuire DA, Hendricks SD, Grinstead GL. Use of an endoscopic aimer for femoral tunnel placement in anterior cruciate ligament reconstruction. *Arthroscopy* 1996;12:26-31.
8. Clancy WG, Devon AN, Reider B, Narechania RG. Anterior cruciate ligament reconstruction using one-third of the patellar ligament, augmented by extra-articular tendon transfers. *J Bone Joint Surg Am* 1982;64:352-359.
9. O'Brien WR. Isometric placement of anterior cruciate ligament substitutes. *Oper Tech Orthop* 1992;2:49-54.
10. Hoogland T, Hillen B. Intra-articular reconstruction of the anterior cruciate ligament. *CORR* 1984;185:197-202.
11. O'Brien WR, Friedrich NF, Muller W, Henning CE. Functional anatomy of the cruciate ligaments. Presented at the Meeting of the Arthroscopy Association of North America, February 1992.
12. Kieffer DA, Curnow RJ, Southwell RB, Tucker WF, Kendrick KK. Anterior cruciate ligament arthroplasty. *Am J Sports Med* 1984;12:301-312.
13. Howell SM, Clark JA, Farley TE. A rationale for the predicting of anterior cruciate graft impingement by the intercondylar roof. *Am J Sports Med* 1991;19:276-282.
14. Howell SM. Arthroscopic roofplasty: A method for correcting an extension deficit caused by roof impingement of an anterior cruciate ligament graft. *Arthroscopy* 1992;8:375-379.
15. Howell SM, Clark JA. Tibial tunnel placement in anterior cruci-

**TABLE 3. Tibial Tunnel Placement**

AP Diameter	Backset	Approximate Patient Proportion
<50 mm	5 mm	16.7%
50-60 mm	6 mm	66.6%
>60 mm	7 mm	16.7%

- ate ligament reconstructions and graft impingement. *CORR* 1992;283:187-195.
16. Howell SM, Clark JA, Farley TE. Serial magnetic resonance study assessing the effects of impingement on the MR image of the patellar tendon graft. *Arthroscopy* 1992;8:350-358.
  17. Yaru NC, Daniel DM, Penner D. The effect of tibial attachment site on graft impingement in an anterior cruciate ligament reconstruction. *Am J Sports Med* 1992;20:217-220.
  18. Berns GS, Howell SM. Roofplasty requirements in vitro for different tibial hole placements in anterior cruciate ligament reconstruction. *Am J Sports Med* 1993;21:292-298.
  19. Howell SM, Taylor MA. Failure of reconstruction of the anterior cruciate ligament due to impingement by the intercondylar roof. *J Bone Joint Surg Am* 1993;75:1044-1055.
  20. Graf B. Isometric placements of substitutes for the anterior cruciate ligament. In: Jackson DW, Drez D, eds. *The anterior cruciate deficient knee: New concepts in ligament repair*. St. Louis: Mosby, 1987;102-113.
  21. Penner DA, Daniel DM, Wood P, Mishra D. An in vitro study of anterior cruciate ligament graft placement and isometry. *Am J Sports Med* 1988;16:238-243.
  22. Good L, Odenstein M, Gillquist J. Precision in reconstruction of the anterior cruciate ligament. A new positioning device compared with hand drilling. *Acta Orthop Scand* 1987;58:658-661.
  23. Staeubli H, Rauschnig W, Berg P, Porcellini B. Morphometric criteria for anatomic intraarticular ACL reconstruction. Presented at the Annual Meeting of the American Academy of Orthopaedic Surgeons, February 1995, Orlando, Florida.
  24. Khalfayan EE, Bruckner JD, Sharkey PF, Bynum EB, Alexander AH. The relationship of tunnel placement and clinical outcome following anterior cruciate ligament reconstruction. Presented at the Annual Meeting of the American Academy of Orthopaedic Surgeons, February 1994, New Orleans, Louisiana.
  25. Goble EM. Fluoroarthroscopic allograft anterior cruciate reconstruction. *Tech Orthop* 1988;2:65-73.
  26. Jackson DW, Gasser SI. Tibial tunnel placement in ACL reconstruction. *Arthroscopy* 1994;10:124-131.
  27. Howell SM, Barad SJ. Knee extension and its relationship to the slope of the intercondylar roof. *Am J Sports Med* 1995;23:288-294.
  28. Morgan CD, Kalman VR, Grawl DM. Definitive landmarks for reproducible tibial tunnel placement in anterior cruciate ligament reconstruction. *Arthroscopy* 1995;11:275-288.
  29. Noyes FR, Keller CS, Grood ES. Advances in the understanding of knee ligament injury, repair and rehabilitation. *Med Sci Sports Exerc*. 1984;16:427-43.
  30. Hefzy MS, Grood ES, Noyes FR. Factors Affecting the Region of Most Isometric Femoral Attachments. Part II: The Anterior Cruciate Ligament. *AJSM* 1989;17:208-216.
  31. Odenstein M, Gillquist J. Functional Anatomy of the Anterior Cruciate Ligament and a Rationale for Reconstruction. *JBJS* 1985;67:257-262.
  32. Mueller W. *The knee*. Berlin: Springer-Verlag, 1983.
  33. Good L, Odenstein M, Gillquist J. Intercondylar Notch Measurements with Special Reference to Anterior Cruciate Ligament Surgery. *CORR*, 1991;263:185-189.
  34. McGuire DA. Anterior cruciate ligament reconstruction. Presented at the Arthroscopy Association of North America Specialty Day, San Francisco, CA, 1993;133-137.