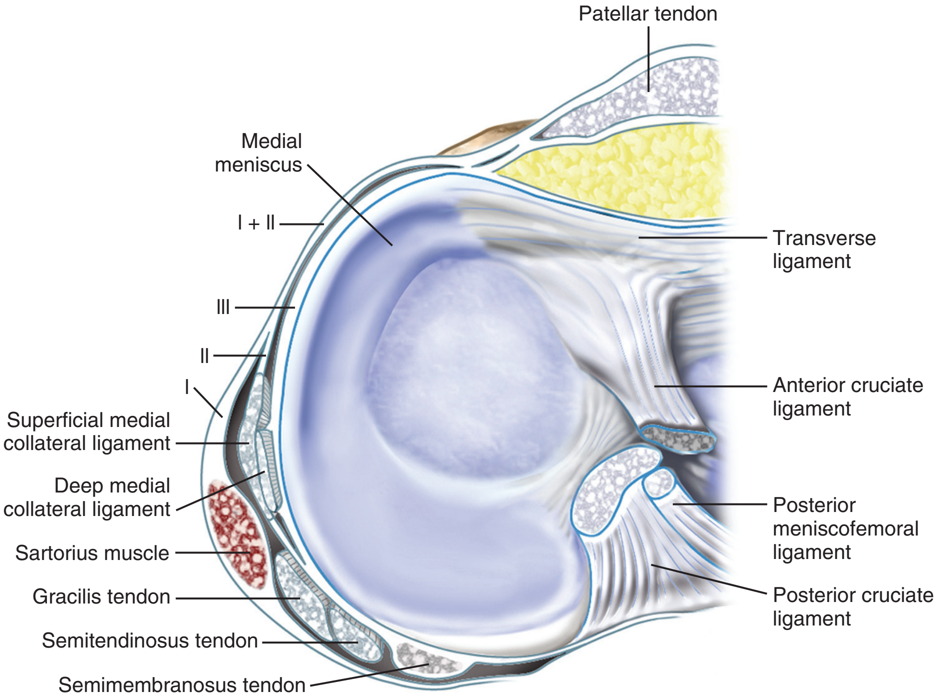

FIG 1-1 Medial layers of the knee. The gracilis and semitendinosus lie between layers 1 and 2.

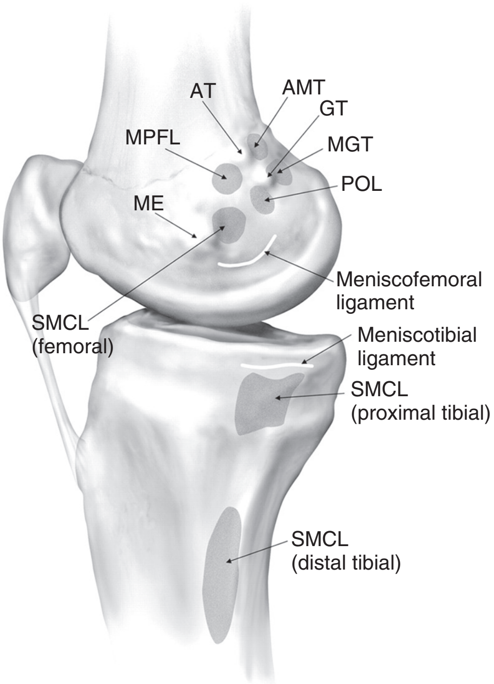

FIG 1-2 The femoral osseous landmarks and attachment sites of the main medial knee structures. *AT,* Adductor tubercle; *AMT*, adductor magnus tendon; *GT*, gastrocnemius tubercle; *ME*, medial epicondyle; *MGT*, medial gastrocnemius tendon; *MPFL*, medial patellofemoral ligament; *POL*, posterior oblique ligament; *SMCL*, superficial medial collateral ligament. (From LaPrade RF, Engebretsen AH, Ly TV, et al. The anatomy of the medial part of the knee. *J Bone Joint Surg.* 2007;89A:2000-2010.)

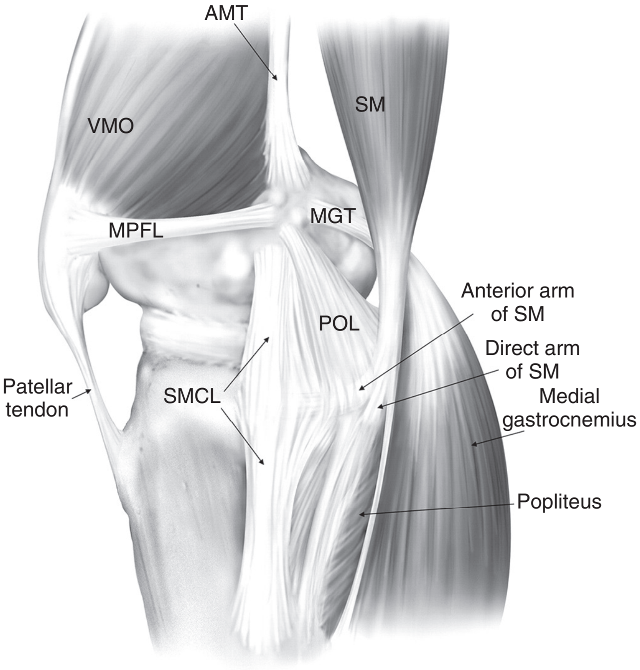

FIG 1-3 The main medial knee structures (right knee). *AMT*, Adductor magnus tendon; *MGT*, medial gastrocnemius tendon; *SM*, semimembranosus muscle; *SMCL*, superficial medial collateral ligament; *MPFL*, medial patellofemoral ligament; *POL*, posterior oblique ligament; *VMO*, vastus medialis obliquus. (From LaPrade RF, Engebretsen AH, Ly TV, et al. The anatomy of the medial part of the knee. *J Bone Joint Surg.* 2007;89A:2000-2010.)

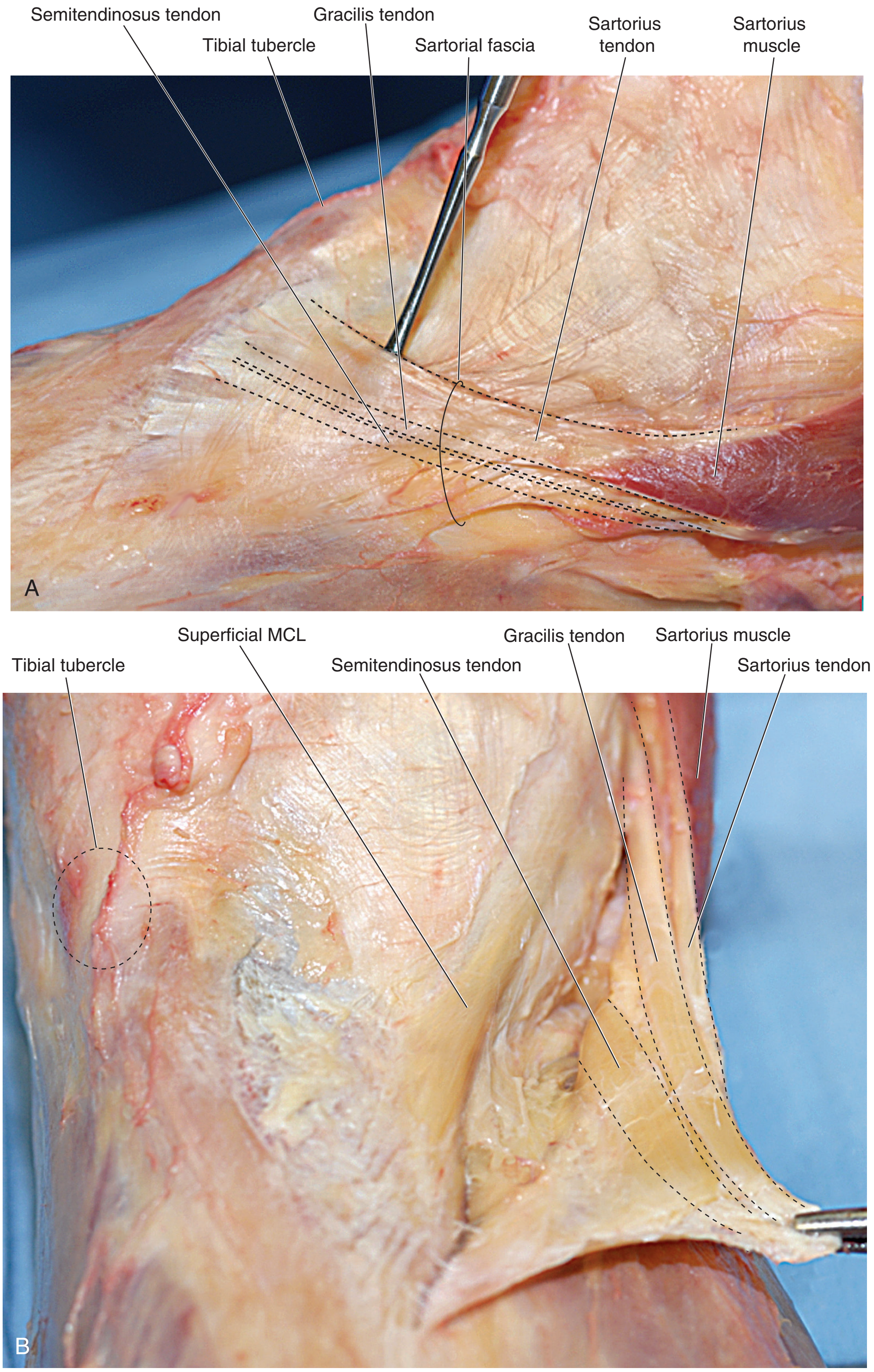

FIG 1-4 **A,** Sartorius fascia of layer 1 overlying the gracilis and semitendinosus tendons. **B,** Gracilis and semitendinosus tendons within pes anserine fascia. *MCL,* medial collateral ligament.

authors concluded that allograft remodeling is much slower than autograft and suggested that patients who receive allografts should probably be protected against maximum activities for a longer period of time than those who receive autografts.

In another study in which freeze-dried bone-ACL-bone allografts were implanted, Jackson and associates[41] reported that the maximum load of the allografts was only 25% of the contralateral ACL controls at 1 year postimplantation. Figure 4-30 summarizes a number of allograft ACL reconstruction studies and demonstrates that all had mechanical properties in low ranges from 4 to 52 weeks postoperative. The healing effects of autografts and allografts are covered in greater detail in Chapter 5.

Our laboratory[27,70,72] has studied the effects of gamma irradiation on the mechanical and material properties of allografts in the goat model and in human cadavers. In the first study, Gibbons and colleagues[27] reported on the effects of 2 and 3 mrad of gamma irradiation on goat ACL B-PT-B in vitro properties. The study reported that the maximum stress, maximum strain, and strain energy were significantly reduced after 3 mrad; however, there were no significant reductions after 2 mrad of irradiation (Table 4-10).

In a second study, the effects of a higher level of irradiation (4 mrad) were studied on human cadaver donor (aged 18 to 59 years) frozen patellar tendon-bone allografts and were compared with a frozen control graft (0 mrad).[70] Irradiation produced a small, but significant, decrease in graft length (0.6 mm, $P < .01$; Table 4-11). The irradiated grafts showed significant reductions in stiffness ($P < .025$) and maximum force ($P < .001$).

In a third study, Salehpour and associates[72] studied the effects of 4, 6, and 8 mrad (40,000, 60,000, or 80,000 Gy) of gamma irradiation on the in vitro properties of a B-PT-B allograft unit retrieved from mature female goats. On average, stiffness decreased by 18%, 40%, and 42% at 4, 6, and 8 mrad, respectively ($P < .05$ for all comparisons). The data

CRITICAL POINTS Allografts and Autografts: Biomechanical Properties After Implantation and Effect of Irradiation

The majority of experimental studies demonstrate that allografts have inferior results compared with autografts (and contralateral controls) in regard to mechanical strength properties. The effects of gamma irradiation on the mechanical and material properties of allografts have been studied in the goat model and human cadavers for many years.

- Effects of 2 and 3 mrad of gamma irradiation on goat ACL bone-patellar tendon-bone in vitro properties showed maximum stress, maximum strain, and strain energy were significantly reduced following 3 mrad; however, there were no significant reductions following 2 mrad of irradiation.
- Effects of 0 versus 4 mrad of gamma irradiation on human cadavers: irradiation produced a small, but significant, decrease in graft length (0.6 mm). Irradiated grafts showed significant reductions in stiffness and maximum force.
- Effects of 4, 6, and 8 mrad on goat ACL bone-patellar tendon-bone units: data showed the overall dose-dependent effects of irradiation on ligament mechanical properties; doses less than 2 mrad had minimal effects.
- In vivo effect of 4 mrad of gamma irradiation on bone-patellar tendon-bone units in goats at time 0 and 6 months postimplantation: irradiation significantly altered structural but not material properties.

At present, there are no experimental data to show that the low-dose irradiation as used to secondarily sterilize allografts has a deleterious effect on graft mechanical properties.

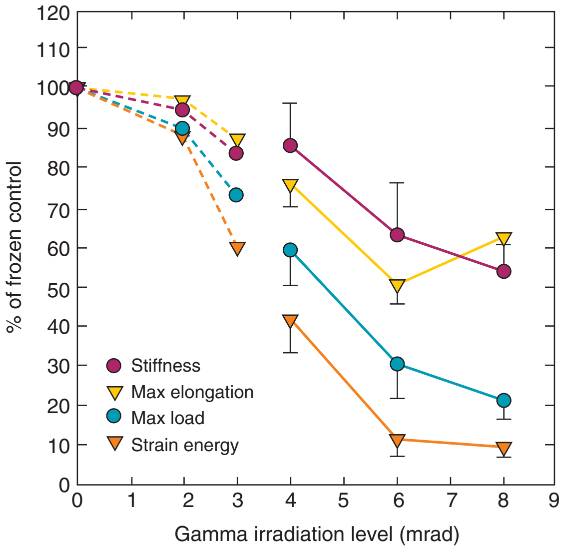

FIG 4-30 Average dose-dependent response curves for all four mechanical properties (*solid lines*), expressed as percentages of values for contralateral frozen controls. Normalized data for 2 and 3 mrad (*dashed lines*) from earlier studies are also shown. Those studies used different testing conditions. Note the nearly linear declines in all curves between 2 and 6 mrad. (From Salehpour A. Butler DL. Proch FS, et al. Dose-dependent response of gamma irradiation on mechanical properties and related biochemical composition of goat bone-patellar tendon-bone allografts. *J Orthop Res.* 1995;13:898-906.)

TABLE 4-10 Dose-Dependent Effects of Gamma Irradiation on Composite Unit Structural Mechanical Properties

Composite Unit	*n*	Stiffness (N/mm)*	Max Force (N)*	Max Elongation (mm)*	Strain Energy (N-m)*
Frozen control	24	189.9 ± 33.6	1406.1 ± 363.8	10.2 ± 1.5	8.2 ± 3.2
2 mrad	12	179.3 ± 23.9	1261.8 ± 252.1	9.9 ± 1.8	7.2 ± 3.0
3 mrad	12	158.2 ± 14.3†	1206.2 ± 101.2‡§	8.9 ± 1.3¶	4.9 ± 1.1†‡

Data are presented as means ± standard deviation.
*$P < .05$ compared with control (based on one-sided Dunnett multiple comparison of irradiated to control).
†$P < .005$ compared with control (based on contrasts for individual variables).
‡$P < .05$ compared with control (based on analysis of variance for all variables).
§$P < .0005$ compared with control (based on contrasts for individual variables).
¶$P < .05$ compared with control (based on contrasts for individual variables).
From Gibbons MJ, Butler DL, Grood ES, et al. Effects of gamma irradiation on the initial mechanical and material properties of goat bone-patellar tendon-bone allografts. *J Orthop Res.* 1991;9:209-218.

TABLE 4-11 Effects of 4 mrad Irradiation on Human Patellar Tendon-Bone Allograft Length and Mechanical Properties

	Allograft Length Before Irradiation (mm)	Allograft Length After Irradiation (mm)	Static Creep* (mm)	Peak Cyclic Creep† (mm)	Stiffness (kN/m)	Maximum Load (N)
Control	58.0 ± 6	—	0.4 ± 0.3	0.4 ± 0.2	311 ± 51	2549 ± 434
Irradiated	57.6 ± 6	57.0 ± 6	0.5 ± 0.3	0.5 ± 0.3	275 ± 52	1884 ± 330
Number of pairs	18	18	20	20	20	16
Significance (*P*)	—	.01‡	—	—	.025	.001

From Rasmussen TJ, Feder SM, Butler DL, Noyes FR. The effects of 4 mrad of gamma irradiation on the initial mechanical properties of bone-patellar tendon-bone grafts. *Arthroscopy.* 1994;10:188-197.
*Measured at 90-N force after 10 min.
†Measured at 200-N force after 3600 cycles at 1 cycle/sec.
‡Preirradiation to postirradiation.

TABLE 4-12 Structural Properties of Anterior Cruciate Ligament Allografts 6 Months Postimplantation in Caprine Model

	Linear Stiffness (KN/m)	Maximum Force (N)	Elongation to Failure (mm)	Energy to Maximum Force (N-m)
0 mrad	123.2 (45.4)*	496.6 (144.6)*	8.2 (2.7)	1.6 (0.8)
4 mrad	86.3 (32.5)*	392.0 (165.2)*	7.6 (1.3)	0.9 (0.3)
0 mrad as a percentage of normal ACL†	16.8 (732)	19.8 (2506)	172.1 (4.8)	29.8 (5.3)
4 mrad as a percentage of normal ACL†	11.8	15.6	158.9	17.9

From Schwartz HE, Matava MJ, Proch FS, et al. The effect of gamma irradiation on anterior cruciate ligament allograft biomechanical and biochemical properties in the caprine model at time zero and at 6 months after surgery. *Am J Sports Med.* 2006;34:1747-1755.
Values are mean (standard deviation), n = 12.
**P* < .05 between 0-mrad and 4-mrad groups.
†Mean values for normal ACL based on prior published literature.

as a whole showed the overall dose-dependent effects of irradiation on ligament mechanical properties. Doses less than 2 mrad have minimal effects. Schwartz and coworkers[75] examined the in vivo effect of 4 mrad of gamma irradiation on B-PT-B units in adult goats at time 0 and 6 months postimplantation. The irradiation significantly altered structural but not material properties. Stiffness was reduced by 30% and maximum force by 21%, resulting in these parameters averaging 12% to 20% of normal ACL values (Table 4-12).

We concluded that 4 mrad of gamma irradiation affect ACL allograft subfailure viscoelastic and structural properties but not material or biochemical properties over time.[70,72,75] The ACL allografts of the 0 mrad failed at 497 N (see Table 4-9), which in comparison with the first study of Gibbons and associates[27] showed a control graft of 1400-N maximum force. This suggests that the effects of the remodeling process, resulting in a weakened graft with altered mechanical properties as previously described, produced even more profound deleterious effects than the irradiation treatment.

Bhatia and colleagues[8] reported that maximal load and stiffness in a rabbit ACL model, using tendon allografts and autografts, were unaltered by low-dose (1.2 mrad) gamma irradiation. They concluded that low-dose gamma irradiation was safe for sterilization of soft tissue ACL allografts. Yanke and colleagues[98] studied cyclic and failure properties of human B-PT-B allografts treated with 1.0 to 1.2 mrad compared with paired untreated specimens and found no significant difference in biomechanical properties except for decreased in graft stiffness of 20%. They concluded that low-dose irradiation was not deleterious to preimplantation mechanical properties. Recent interest in electron-beam irradiation, rather than gamma irradiation, is noted in Hoburg and associates' investigation.[36] This sterilization process demonstrated a minimal effect on B-PT-B ACL allograft strain, cyclic elongation, stiffness, and failure and may provide a higher level of safety.

The published results of studies showing the delayed healing of allografts and low ultimate strength properties even at 1 year in the animal model are consistent with clinical observation in humans of the higher failure rate of ACL allografts, and we recommend to use autograft tissues whenever possible in ACL surgery. These concepts are further discussed in Chapters 7 and 8. We prefer to obtain allografts for patients from tissue banks that use secondary chemical sterilization for bacterial contamination.

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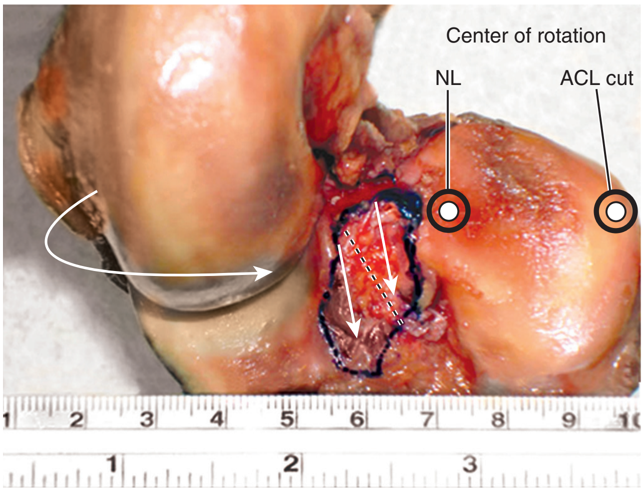

FIG 7-24 The anterior cruciate ligament (ACL) attachment on the tibia is outlined, along with an approximated center of tibial rotation. After ACL sectioning, the center of tibial rotation shifts medially, restrained in part by the medial ligament structures. The ACL tibial fibers are divided into anteromedial and posterolateral bundles. It should be noted that the anteromedial bundle is anatomically positioned to limit the coupled motions of internal tibial rotation and anterior translation under loading conditions; this effect has been frequently underestimated in biomechanical studies. *NL,* Normal.

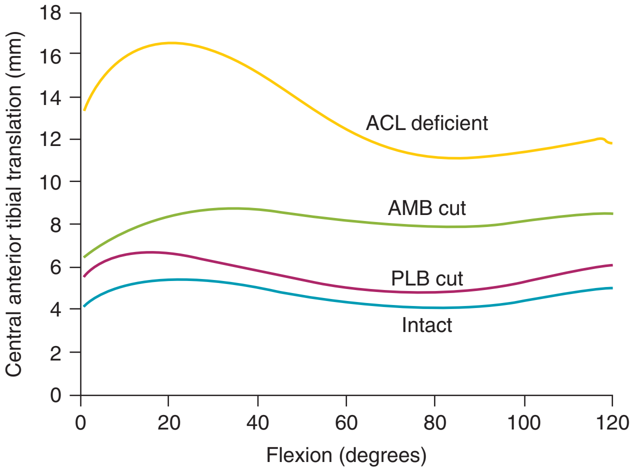

FIG 7-25 Anterior tibial translation of the central tibiofemoral compartment under a 100-N anterior load test from 0 to 120 degrees of flexion for intact, posterolateral bundle (PLB) cut, anteromedial bundle (AMB) cut and anterior cruciate ligament (ACL) deficient conditions. (From Gardner EJ, Noyes FR, Jetter AW, et al. *Effect of anteromedial and posterolateral ACL bundles on resisting medial and lateral tibiofemoral compartment subluxations. Arthroscopy.* 2015;31(5):901-910.)

particularly in a single-graft construct. Thus, the advantage of a double-graft construct (either ACL or PCL) is to restore normal knee motion limits under the lowest graft tensile loads, which is advantageous during graft healing and remodeling. A graft under lower loads has the theoretical advantage of less risk in stretching out with return of the abnormal motion limits. In addition, an ACL or PCL graft under higher tension, under cyclic loading conditions, is at high risk of graft stretching and failure.[261] Again, it should be noted that either one or two ACL grafts does not restore native ACL fiber length-tension properties.

Our Robotic Studies on Anterior Cruciate Ligament Anteromedial Bundle and Posterolateral Bundle Function and Single Anterior Cruciate Ligament Graft Reconstruction

We conducted a series of robotic cadaveric in vitro studies on the kinematic function of the AM and PL bundles of the ACL.[78,91,209] The studies involved a six-DOF robotic testing protocol on intact knees, knees in which either the AM or PL bundle was sectioned, and knees in which complete ACL sectioning was performed. As previously described, the robotic testing protocol involved, for the first time, the simulation of the pivot shift event using four DOF; namely, anterior tibial translation with internal tibial rotation with valgus loading of the limb during knee flexion-extension to induce maximum anterior tibial subluxation. The studies also involved, for the first time, digitization of the tibial plateau to determine medial and lateral tibiofemoral compartment translations and centers of tibial rotation in the simulated pivot shift test.

The results showed both ACL bundles functioned synergistically to resist medial and lateral compartment subluxations during the simulated Lachman and pivot shift tests. The AM bundle provided more restraint to anterior tibial translation under both tests than the PL bundle. Both ACL bundles had to be sectioned to produce tibiofemoral compartment subluxations during pivot shift loading (Figs. 7-25, 7-26, and 7-27). Neither bundle contributed to resisting internal rotation during pivot shift loading tests. We concluded that an ACL graft designed to duplicate the AM bundle restores medial and lateral compartment translations under multiple loading conditions; however, the PL bundle only provides a back-up restraint at low flexion angles. Neither ACL bundle resists internal tibial rotation or, in its absence, allows a positive pivot shift subluxation. Furthermore, the PL bundle is not the primary restraint for providing rotational knee stability, as has been quoted in the literature.[110,120,124]

We conducted a robotic cadaveric in vitro study that found that a single ACL graft placed into the anatomic center of the femoral and tibial attachment sites restored normal tibiofemoral compartment translations and rotations under simulated Lachman and pivot shift testing conditions. The study involved a six-DOF robotic testing protocol on intact knees, ACL-sectioned knees, and ACL-reconstructed knees. The reconstruction restored rotational stability as defined by normal motion limits and normal medial and lateral compartment translations under simulated pivot shift loading conditions (Fig. 7-28).

The results of this study support the recommendations in this chapter on the use of a single ACL graft instead of a double-bundle ACL graft construct. This finding is supported by Markolf and associates[166] who studied the effect of single- and double-bundle ACL grafts in cadaveric knees. As described in this chapter, prior robotic pivot shift studies on double-bundle ACL reconstructions used loading profiles that did not involve a coupled anterior tibial translation and internal rotation to induce maximum anterior tibial subluxations, and, in addition, did not measure resulting tibiofemoral compartment translations or subluxations. We question the validity of these studies in terms of the conclusions that a single ACL graft does not restore knee rotational stability or that a double-bundle ACL construct is required.

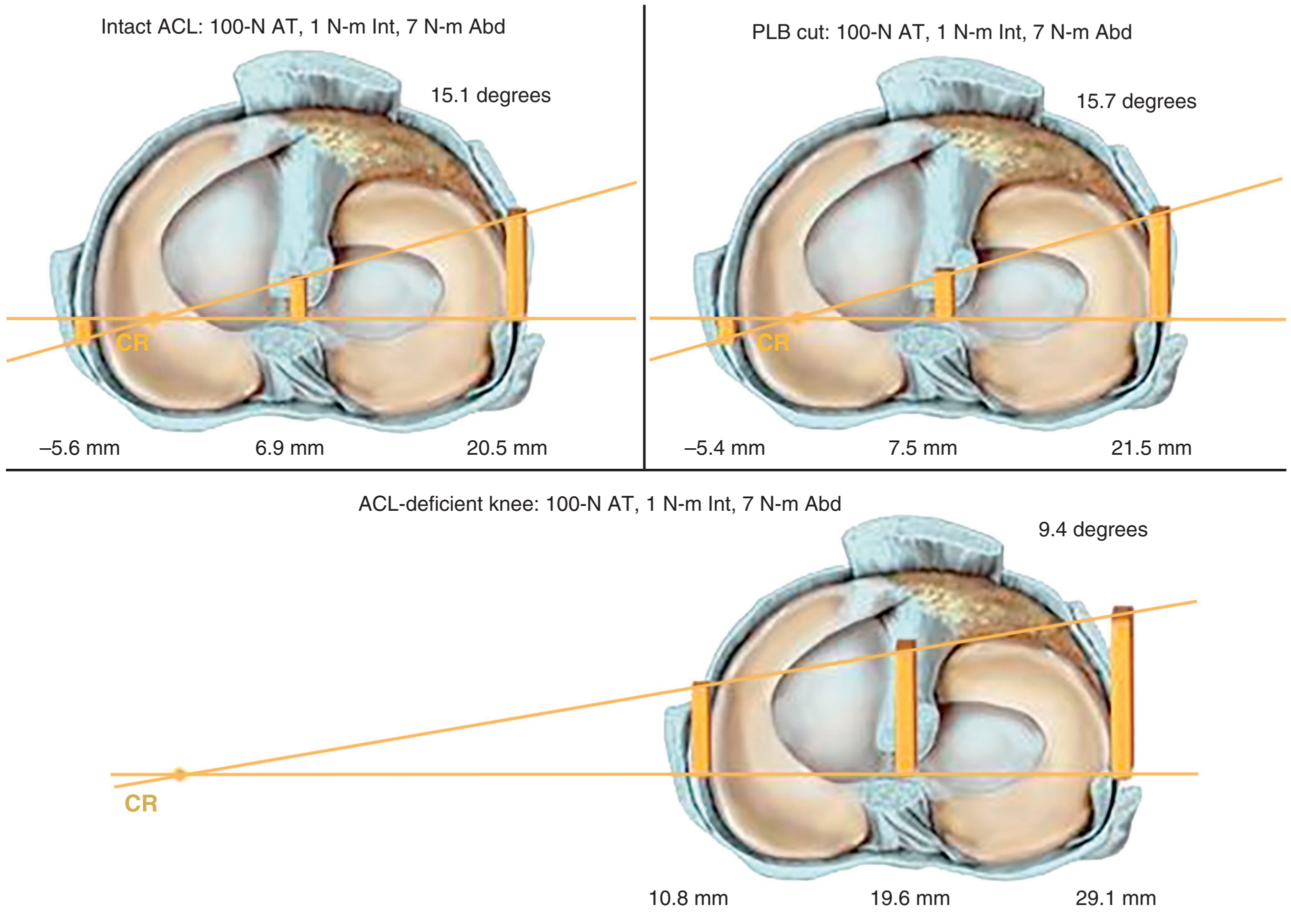

FIG 7-26 A representative right knee specimen showing compartment translations and tibial rotation under pivot shift 4 loading conditions (100-N anterior, 1 N-m internal rotation, 7 N-m valgus) for intact, posterolateral bundle (PLB) cut, and anterior cruciate ligament (ACL)-deficient states. PLB sectioning alone resulted in no statistically significant change in tibiofemoral compartment translations. *Abd*, Abduction; *AT*, anterior translation; *CR*, center of tibial rotation; *Int*, internal. (From Gardner EJ, Noyes FR, Jetter AW, et al. Effect of anteromedial and posterolateral ACL bundles on resisting medial and lateral tibiofemoral compartment subluxations: *Arthroscopy*. 2015;31(5):901-910.)

Clinical Measurement of Anterior Cruciate Ligament Graft Function During and After Anterior Cruciate Ligament Surgery

The assessment of ACL graft function must take into account the restoration of the normal coupled motion limits of anterior tibial translation and internal tibial rotation during the pivot shift phenomenon, which strongly correlates with patient giving-way symptoms. During KT-2000 (MEDmetric) testing, only anterior tibial translation is assessed. If the knee joint has a 3-mm or lower increase in central anterior tibial translation over the opposite knee, it can be assumed that there is no positive pivot shift because this amount of constraint to anterior tibial translation also limits anterior subluxation of the lateral tibial plateau. Conversely, if a greater than 5-mm increased anterior tibial translation exists, there may occur a positive pivot shift test and patient complaints of giving-way. The problem is in knees that demonstrate 3 to 5 mm of increased anterior tibial translation, which may represent 20% to 30% of patients in clinical investigations,[1,14,218,259,260] especially when allografts are used.[203] This mild to moderate increase in anterior tibial translation results in a mildly positive Lachman test with a hard endpoint. However, these knees may demonstrate a positive pivot shift and giving-way symptoms. Since the pivot shift test is highly subjective and variable among examiners (see Chapter 3), an author may report a successful result based on the KT-2000 (anterior tibial translation) or a pivot shift test, whereas another examiner may grade the knee as a failure, based on the method in which the pivot shift test is performed. There is a pressing need for clinical examination methods that simulate the pivot shift phenomenon and the resultant subluxations (in millimeters) of the medial and lateral tibiofemoral compartments.

Bull and associates[35] were among the first authors to report intraoperative measurement of tibial translations and rotations using a 3-dimensional motion analysis system. In the operative setting, there was a marked variability in knees in the amount of medial and lateral tibial plateau displacements during the pivot shift test. Robinson and colleagues[245] performed an ACL double-bundle reconstruction using computerized navigation techniques in 22 patients. The exact location of ACL grafts and the loads applied by the examiner are variables still to be determined.

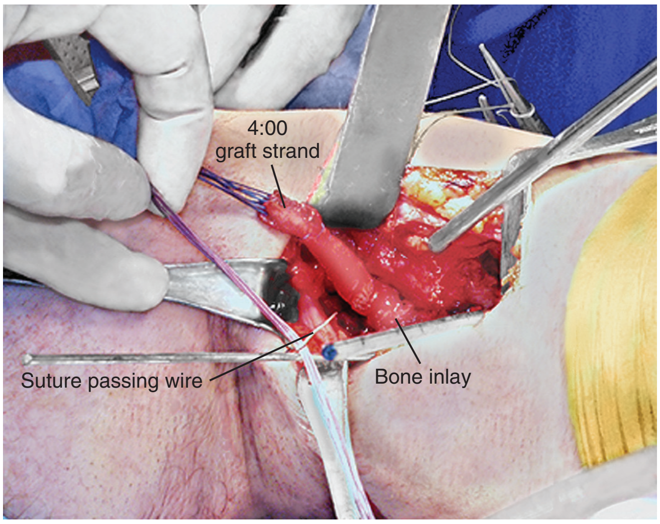

FIG 16-43 Surgical exposure shows placement of the quadriceps tendon autograft. The rectangular bone portion of the graft has been fixated to the proximal tibia with two 4.0-mm partially threaded cancellous screws. The sutures on the medial and lateral graft strands will be pulled intraarticularly with the suture-passing wires. The graft strands lay directly against the posterior tibia, recreating the normal anatomic posterior cruciate ligament tibial attachments. (From Noyes FR, Medvecky MJ, Bhargava M. Arthroscopically assisted quadriceps double-bundle tibial inlay posterior cruciate ligament reconstruction: an analysis of techniques and a safe operative approach to the popliteal fossa. *Arthroscopy*. 2003;19:894-905.)

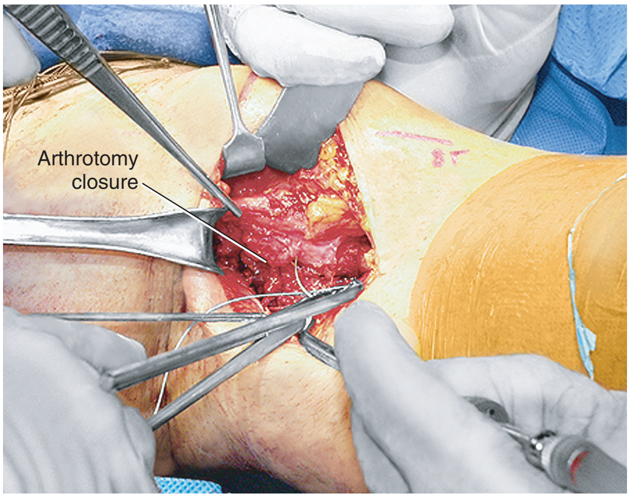

FIG 16-44 Surgical exposure shows the closure of the semimembranosus sheath and posterior arthrotomy. The skin incision is only partially closed at this point to allow for potential fluid extravasation during the final arthroscopic portion of the procedure. (From Noyes FR, Medvecky MJ, Bhargava M. Arthroscopically assisted quadriceps double-bundle tibial inlay posterior cruciate ligament reconstruction: an analysis of techniques and a safe operative approach to the popliteal fossa. *Arthroscopy*. 2003;19:894-905.)

dressing. The lower extremity is placed in a soft hinged knee brace locked at 5 degrees of flexion, with a 3-inch cotton roll placed behind the proximal calf to prevent posterior sagging of the tibia. The neurovascular status is confirmed to be normal before leaving the operating room.

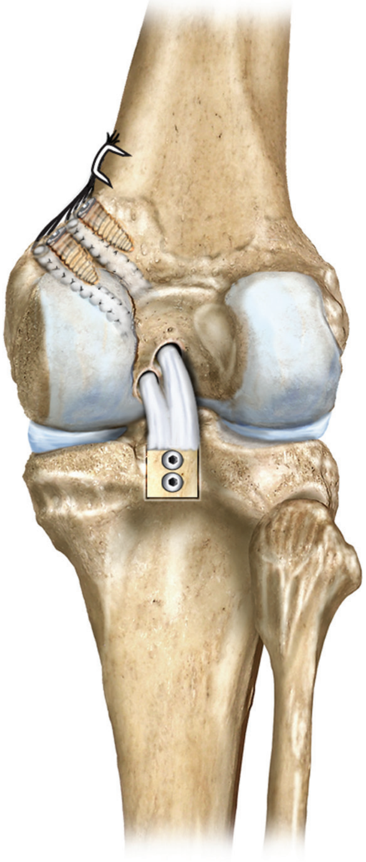

FIG 16-45 The final tibial and femoral fixation of the quadriceps tendon-patellar bone two-strand graft.

Posterior Cruciate Ligament Avulsion Fractures

Avulsion fractures of the PCL are rare, and treatment options depend on the type and size of the fracture, displacement, comminution, and orientation of the fragment.[67,234] These injuries typically occur at the tibial attachment and may involve a small area at the posterior region of the attachment or a large area that extends anteriorly and outside the PCL attachment. Griffith and colleagues[67] reported that the entire insertion area was avulsed in all 19 skeletally mature patients in their series of PCL avulsion fractures. The avulsion fracture is usually obvious on routine radiographs. Occasionally, a computerized tomography scan or MRI is required to define the extent of the facture pattern in major avulsion fractures extending into the joint.[28,67] Avulsion or peel-off PCL injuries at the femoral site have been reported in the literature, but are rare.[62,125,176,186,232]

Patients who have small, partial PCL avulsion fractures, with a negative posterior translation test at 90 degrees of knee flexion, are kept in a brace locked in full extension and remain partial weight bearing for 4 weeks to allow healing. The brace is removed for gentle range of motion (avoiding posterior tibial translation) and quadriceps exercises as described in Chapter 18. Overall, the prognosis for healing and PCL function is good to excellent in these cases.[246]

Complete avulsion of the PCL attachment at the tibia, and less frequently, at the femoral attachment (peel-off avulsion) with posterior tibial subluxation, is an indication for surgical repair. Authors have reported favorable clinical results with the open reduction and internal fixation of PCL avulsion fractures at the tibial insertion site.[8,84] For

CRITICAL POINTS **Posterior Cruciate Ligament Avulsion Fractures**

- Treatment based on type and size of the fracture, displacement, comminution, orientation of fragment.
- Small, partial avulsion fractures, negative posterior translation at 90 degrees of knee flexion: brace locked full extension, protected motion, partial weight bearing for 4 weeks to allow healing.
- Complete avulsion fractures: surgical repair. Use either arthroscopic or open technique based on experience.
- Large and medium avulsion fractures: arthroscopic approach, cannulated screw fixation.
- PCL tibial avulsions with small bony fragments: consider open posterior medial tibial approach.
- Peel-off PCL rupture from femoral attachment: repair PCL attachment with sutures passed through small drill holes, avoid physeal plate when still open.
- Our preferred technique: arthroscopic-assisted approach, repair PCL fibers to approximate broad elliptical femoral attachment.
- Postoperative protocol suture repair maximum protection, early motion by therapist.

instance, Inoue and associates[84] reported on 31 patients followed for 2 to 8 years and noted low side-to-side differences (<5 mm, KT-2000) after surgery. The majority of knees showed a mild residual posterior knee displacement (mean, 3.0 mm). Along with the tibial avulsion, an abnormal MRI signal intensity may be observed within the PCL fibers, indicating partial tearing.

More recently, several authors have described arthroscopic techniques for PCL tibial avulsion fractures.[28,36,70,81,105,201,225,240,246] Gui and associates[70] treated 28 patients using two posteromedial portals and a single tibial tunnel to facilitate suture passage and seating of the bony fragment. The knees were casted for 2 weeks unless a concomitant tibial plateau fracture was present, which necessitated 4 weeks of immobilization. The fractures healed a mean of 2.8 months postoperatively. At 1 year postoperative, four of 20 cases followed had arthrofibrosis, two of whom underwent arthroscopic release. The posterior drawer test was negative in all but one knee. International Knee Documentations Committee (IKDC) rating system[78] results were normal in 20 and nearly normal in four patients.

Zhao and colleagues[246] treated 29 patients with PCL tibial avulsion fractures. The PCL and bony fragment were arthroscopically fixed with sutures that were pulled out through Y-shaped bone tunnels and fixed on a titanium button. Immediate knee motion and partial weight bearing were allowed in a brace that was used for the first 4 weeks. Four patients required a manipulation 3 months after surgery for flexion limitations. At follow-up (>2 years postoperatively), all patients except one had a negative posterior drawer test, and all regained full knee motion except for two patients who had 5 degrees of flexion limitations. IKDC results were normal in 28 patients and nearly normal in one patient.

Zhang and associates[245] treated isolated PCL tibial avulsion fractures in 16 patients (mean age, 43 years) with a minimally invasive posteromedial approach and suture anchors. The patients all had displaced fractures that exceeded 1 cm and fracture fragments less than 2 cm in diameter. Plaster splints were used for 4 to 6 weeks. At a mean of 18 months postoperatively, all cases showed satisfactory reduction and bony healing and all but one patient had returned to their former occupation.

Chen and coworkers[36] treated 36 patients with displaced PCL tibial avulsion fractures (>3 mm of upward displacement of the bony fragment) and posterior knee instability of grade II or higher. Arthroscopic reduction and suture fixation of the bone fragments was accomplished through two tibial tunnels. The knees were immobilized in a brace the first postoperative week, followed by 0 to 60 degrees of motion during weeks 2 to 4 and 120 degrees by week 8. All fractures demonstrated union within 3 months. At a mean of 3 years postoperatively, all but three patients were participating in strenuous or moderate activities, 92% rated their knee function as normal or nearly normal, and three patients (8%) were rated as abnormal because of limitations in knee flexion.

The concept of immediate postoperative knee motion is addressed in detail in Chapter 18. The therapist initiates early and protected knee motion within the first postoperative week, applying an anteriorly directed load to protect the relatively weak suture fixation. The use of a posterior calf pad and careful positioning in the brace is required for the first 4 postoperative weeks until suitable healing has occurred. Knees with suture or pin fixation have relatively low tensile strength repairs and require expert postoperative rehabilitation.

The surgeon should select either an arthroscopic or open technique for tibial avulsion fractures based on experience. In general, it is relatively straightforward to use an arthroscopic approach for cannulated screw fixation for large and medium avulsion fractures. For PCL tibial avulsions with small bony fragments that require a combination of sutures and bone fixation, an open posterior tibial approach is favored by the senior author because it provides good exposure and allows for secure fixation.

A peel-off type of PCL rupture from the femoral attachment has been described as a hyperextension knee injury, such as that reported by Mayer and Micheli[142] in a child while jumping on a trampoline or in patients suffering from trauma from motor vehicle accidents.[37,176] This type of PCL rupture directly at the femoral attachment may occur at the fibrocartilaginous junction, with minor associated damage to the bulk of the PCL fibers. The PCL attachment is easily repaired with sutures passed through small drill holes, avoiding the proximal physeal growth plate. Arthroscopic approaches to PCL femoral soft tissues avulsions have been described by several authors,[62,176,186,232] although clinical data remain scarce. Ross and associates[186] described an arthroscopic approach for repair of acute femoral peel-off tears. Three No. 2 nonabsorbable sutures were passed through the PCL substance, through a femoral tunnel at the PCL footprint, and tied over the medial cortex. Park and Kim[176] reported an arthroscopic technique that used two transfemoral tunnels for the anterior strand and two posterior tunnels for suture repair of the posterior strand. These authors noted that femoral avulsion injuries were exceedingly rare.

The senior author's preferred technique for femoral peel-off or proximal PCL repairs is to use an arthroscopic-assisted approach in which two to three guide pin tunnels (small-diameter for sutures) are placed at the anterior and posterior aspects of the PCL footprint, distal to the physis, to fan out the PCL fiber attachment. A VMO-sparing approach is used and respective suture passers are brought into the knee joint. Through a limited medial arthrotomy and under direct visualization using a headlight, multiple nonabsorbable baseball looped sutures are placed at appropriate sites in the PCL fibers to approximate the broad elliptical femoral PCL attachment. The miniarthrotomy has limited morbidity and allows the surgeon to carefully place multiple sutures into the broad PCL fibers. Secure fixation is achieved along with anatomic placement of disrupted PCL fibers.

In PCL injuries that extend away from the femoral attachment and involve the proximal third of the PCL fibers, an augmentation is favored (assuming the growth plate is closed). The postoperative protocol for a direct suture repair should take into account the low repair tensile strength, requiring maximum protection. The knee is

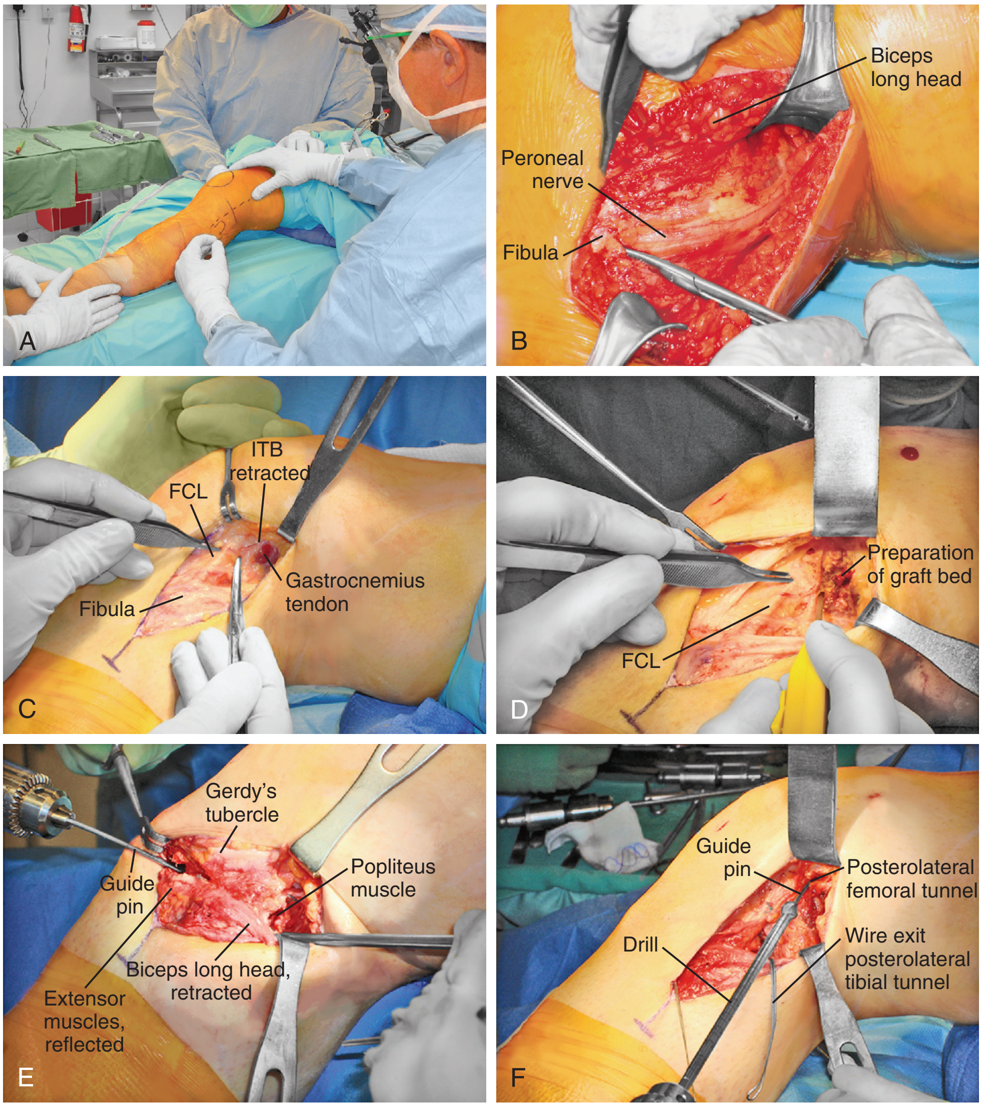

FIG 17-17 Posterolateral capsular reconstruction for severe knee varus recurvatum and hyperextension using an Achilles tendon-bone (AT-B) allograft. **A,** Patient positioning. **B,** Identification of the peroneal nerve at fibular neck. **C,** Identification of fibular collateral ligament (FCL) and popliteus muscle-tendon-ligament, functionally intact. **D,** Exposure of femoral graft site at lateral gastrocnemius tendon attachment. **E,** Placement of the tibial drill hole lateral and distal to the joint line. **F,** Placement of the femoral drill hole.

A straight lateral incision, approximately 12 cm in length, is used centered over the lateral joint line. The surgical approach already described is followed. The incision is extended distally to allow exposure of the fibular head and peroneal nerve and proximally to allow exposure of the attachment of the FCL to the femur. The skin flaps are mobilized beneath the subcutaneous tissue and fascia to protect the vascular and neural supply to the skin. The attachment of the ITB is identified.

An inferior incision is made along the posterior aspect of the ITB and the attachments overlying the biceps muscle. This allows the ITB to be reflected anteriorly so that the anatomy of the PL aspect of the knee is easily visualized.

The CPN is carefully protected throughout the surgical procedure for the drill hole made through the proximal fibula for placement of the FCL graft. It is usually not necessary to dissect the peroneal nerve when its course can be identified; however, if there is any question, it is prudent to dissect the sheath over the nerve around the fibular neck for complete identification.

The fibular head is exposed anteriorly and posteriorly by subperiosteal dissection. Only 12 to 15 mm of the proximal fibula is exposed. A 6-mm drill hole is carefully made anteriorly and posteriorly in the center of the fibular head; a drill guide is used to ensure that soft tissues are protected. A straight curette is used to dilate the 6-mm cortical hole from anterior to posterior, compressing the cancellous bone. Care is taken not to disturb the tibiofibular joint capsule, thereby preserving joint stability.

At the femoral attachment of the FCL, one of two approaches may be selected. In the first approach, the femoral tunnel is made just posterior and superior to the FCL attachment for a single tunnel, with the graft passed into the tunnel by use of a Beath needle. A second approach

FIG 26-17 A 32-year-old woman with abnormal lateral joint opening underwent high tibial osteotomy elsewhere. The preoperative planning failed to account for the abnormal lateral joint opening, which resulted in a severe valgus overcorrection and need for revision osteotomy.

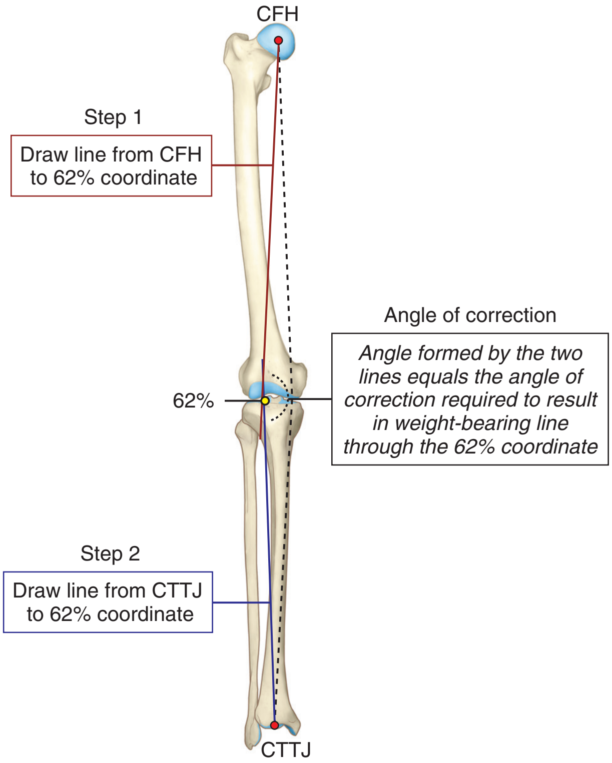

FIG 26-18 The method used to calculate the correction angle of a high tibial osteotomy using a full-length anteroposterior radiograph of the lower extremity. The lines from the centers of the femoral head (CFH) and tibiotalar joint (CTTJ) converge in this example at the 62% coordinate.

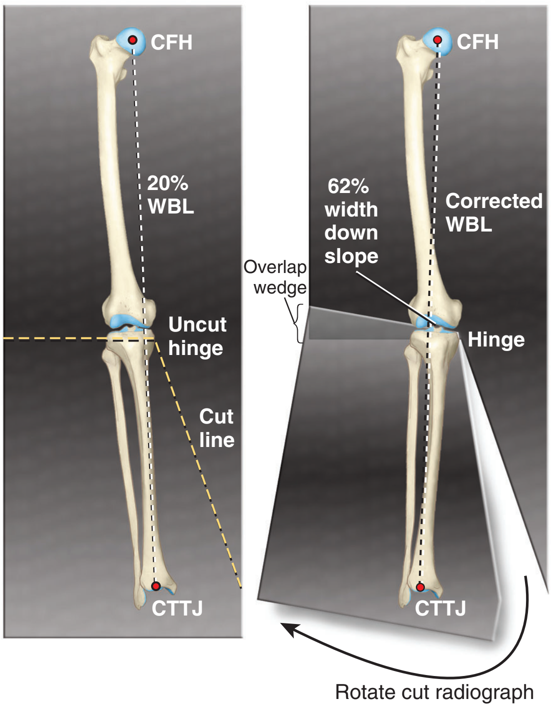

FIG 26-19 An alternative method used to calculate the correction angle of a high tibial osteotomy using a full-length anteroposterior radiograph of the lower extremity. The radiograph is cut to allow the center of the femoral head (CFH), the 62% coordinate, and the center of the tibiotalar joint (CTTJ) to become collinear. The angle of the resulting wedge of radiograph overlap equals the desired angle of correction. The example is provided for a closing wedge osteotomy. The same technique is used for an opening wedge osteotomy in which the medial tibial opening wedge is made to obtain the desired correction. *WBL,* Weight-bearing line.

coordinate position. The angle formed by the two lines intersecting at the tibia represents the angular correction required to realign the WBL through this coordinate. An alternative method was published[60] in which the previously discussed femoral and tibial axis lines intersect at the hinge point of the tibial osteotomy. This technique ends up with a similar measurement for the angular correction. However, the surgeon does not have the measured WBL tibial intersection required for intraoperative fluoroscopy verification.

The second method of determining the correction wedge involves cutting the full-standing radiograph horizontally through the line of the superior osteotomy cut (Fig. 26-19). A vertical cut of the lower tibial segment (opening or closing wedge) is made to converge with the first cut. The distal portion of the radiograph is aligned until the center of the femoral head, the selected WBL coordinate point on the tibial plateau, and the center of the tibiotalar joint are all collinear. With the radiograph taped in this position, the angle of the wedge formed by the overlap of the two radiographic segments is measured and compared with the value obtained using the first method. The mechanical axis is measured to determine the angular correction. If there is a discrepancy between the two correction wedge angles, the procedures should be repeated.

Calculations to Determine Tibial Slope and Clinical Indications to Change Tibial Slope

Lateral radiographs are examined and measurements made of the tibial slope. Abnormal posterior sloping of the tibia in the sagittal plane may

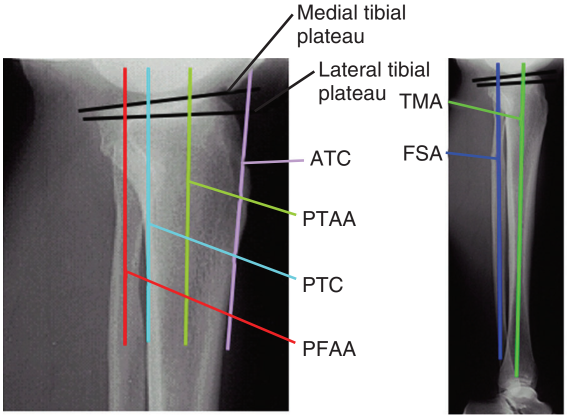

FIG 26-20 Some reported radiographic techniques to measure the tibial slope. The values obtained depend on the anatomic site selected on the tibia. Selected literature references for reported values are shown in Table 26-3. *ATC*, Anterior tibial cortex; *FSA*, fibular shaft axis; *PFAA*, proximal fibular anatomic axis; *PTAA*, proximal tibial anatomic axis; *PTC*, posterior tibial cortex; *TMA*, tibial mechanical axis. (From Noyes FR, Goebel SX, West J. Opening wedge tibial osteotomy: the 3-triangle method to correct axial alignment and tibial slope. *Am J Sports Med.* 2005;33:378-387.)

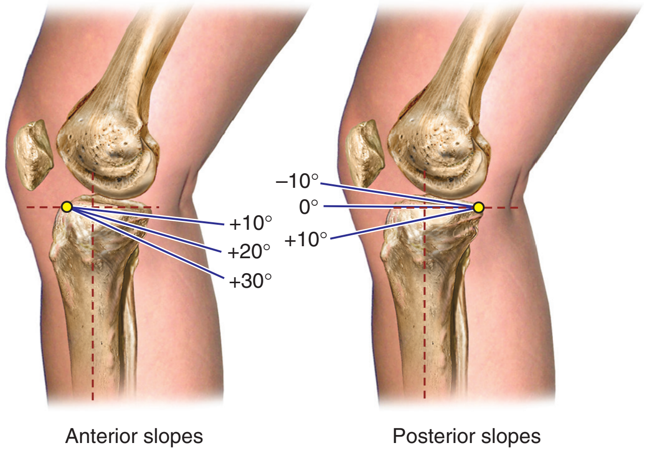

FIG 26-21 The effect of an increase in the tibial slope is shown. The degree of tibial slope is based on proximal tibial anatomic axis.

model the effect of changes in posterior tibial slope on ligament loads and tibial translation and to predict contact pressures of the lateral and medial plateau (under 100-N axial load). The data showed that, at mid stance in the gait model, a change in posterior tibial slope from –5 to +5 degrees resulted in a change in ACL force from –79 to +136 N from the 0 neutral reference point. This corresponded to a change in AP position from –1.2 to +1.2 mm from the 0 neutral position. In comparison, the study by Shelburne and colleagues[191] showed an alteration in posterior tibial slope of –5 to +5 degrees in walking resulted in a change from –75 to +80 N in ACL force, as well as a change from –2.3 to +2.4 mm in anterior tibial translation relative to reference values. Accordingly, these studies show that there is the potential for higher ACL forces on a healing ACL graft substitute with an abnormal tibial slope; however, the increase in forces is in the modest range and well below predicted ACL graft rupture. It would thus be prudent to measure the tibial slope in patients undergoing ACL surgery and determine those outliers (±2 standard deviations) in whom a more conservative rehabilitation program should be used to protect the healing graft in the early to mid postoperative period. This suggestion may even have increased relevance with low-strength ACL grafts that have decreased healing potential, as shown with allografts. Marouane and associates[124] reported in their second finite element model that a 1400-N axial load at 45 degrees of knee flexion at posterior tibial slopes of –5 degrees, neutral 0 degree, and 5 degrees produced calculated ACL forces of 102 N, 181 N, and 317 N, respectively.

Giffin and coworkers[75] reported in cadaveric knees that an increase of 5 degrees in the tibial slope produced an anterior shift in the resting position of the tibia (maximum, 3.6 mm ± 1.4 mm at full extension). However, under a 200-N axial load, there was only a 2-mm anterior shift in the tibiofemoral contact position (30 and 90 degrees) and no increase in ACL forces. The authors concluded that small changes in tibial slope under simulated weight-bearing conditions would have little effect on tibiofemoral position; however, the 200-N axial load does not simulate larger weight-bearing loads with activity.

In a second study conducted by Giffin and associates,[74] a 5-mm anterior opening wedge osteotomy in PCL-sectioned cadaveric knees was performed, and an anterior shift in the tibia resting position of approximately 4 mm was measured. The beneficial effect of an increase in tibial slope in a PCL-deficient knee should be viewed in terms of functional loading conditions, and it is questionable whether the resting no-load position data are applicable to in vivo loading conditions. In this study, under a combined 134-N tibial translation load and 200-N axial compressive load, there was no statistical difference in the amount of posterior tibial subluxation between the PCL-deficient and PCL-deficient osteotomy knees. The data show that the tibia reached a similar abnormal posterior tibial position (mean, 90 degrees AP translation: intact knee, 10 mm; PCL deficient, 20.6 mm; PCL deficient osteotomy, 20.3 mm). The authors concluded that “increasing the tibial slope would improve stability in the PCL-deficient knee”; however, this would be true only for conditions of no posterior tibial loading not expected in functional activities. The data in this study may be viewed from an opposite standpoint to indicate that PCL graft reconstruction is warranted in symptomatic knees because the opening wedge osteotomy is not effective in preventing posterior tibial subluxation under posterior tibial loading conditions.

In cadaveric knees, Agneskirchner and colleagues[4] studied the effect of an opening wedge osteotomy combined with a flexion osteotomy (to change the tibial slope) on tibiofemoral contact pressures and the resultant tibiofemoral position. The study reported that the flexion osteotomy shifted the tibiofemoral contact to a more anterior position (15 degrees of flexion osteotomy, ~5 mm, 30 degrees of knee flexion) that neutralized the effect of sectioning the PCL and reduced pressures of the posterior half of the tibial plateau. The authors suggested in varus-angulated, PCL-deficient knees with associated posterolateral knee ligament injury and knee hyperextension that an associated change in tibial slope would have a beneficial effect. Only quadriceps-induced leg extension loading was used without weight-bearing loads or posterior translational loads that are required to determine the resultant tibiofemoral position under more physiologic loading conditions. The quadriceps loading (to resist the applied external flexion moment) changed with the quadriceps extension force, nearly doubling with the flexion osteotomy (without osteotomy, ~550 N, with 15 degrees of flexion; with osteotomy, ~1100 N quadriceps applied load). In fact, the increased quadriceps loading increased joint contact pressures.

In contrast to the study just discussed, Rodner and coworkers[183] reported in cadaveric knees that an increase in tibial slope in the ACL-deficient knee at the time of an HTO has the potential to redistribute tibiofemoral contact pressures to a more posterior position on the tibial plateau. From a theoretical standpoint, a redistribution of pressures posterior on the tibial plateau would be detrimental to the long-term success of an HTO in ACL-deficient knees with meniscectomy and posterior tibial plateau articular damage. The cadaver knee studies involved uniaxial loading knee joint loads instead of the quadriceps loading in the study by Agneskirchner and colleagues,[4] thereby demonstrating the marked effect that in vitro experimental loading conditions have on joint contact pressures and study conclusions.

Brandon and associates[35] measured the tibial slope in 100 ACL-deficient patients and 100 controls and reported that female and male patients had similar tibial slope measurements. ACL-deficient female and male patients had increases in tibial slope (mean values increased 3.6 degrees and 2.4 degrees, respectively), and the high-grade pivot shift patient group had an increase in tibial slope (mean value increased ~2 degrees). The measurements show high standard deviations (~35% of the mean values), and it is probable that the few degrees difference among patient groups are not clinically significant or would result in increased ACL load and anterior tibial displacement.

Dejour and colleagues[53] evaluated chronic ACL-deficient knees with monopodal lateral weight-bearing films (knee flexed 20 to 30 degrees with the quadriceps contracted) and compared the anterior tibial translation with the tibial slope. The tibial slope was defined as the angle between the medial tibial plateau and the long axis of the tibia, which had an average value of 6 degrees. The anterior tibial translation was defined as the distance between a parallel line at the posterior medial tibial plateau and a posterior point on the medial femoral condyle. The authors reported a statistically significant relationship between the standing anterior tibial translation and the tibial slope in both normal and chronic ACL-deficient knees. The regression line showed a 6 mm increase in anterior tibial translation for every 10-degree increase in tibial slope. However, it should be noted that a wide variation was present in the data between knees. For example, in chronic ACL-deficient knees with a tibial slope of 10 degrees, anterior tibial translation varied from approximately –2 to 12 degrees.

Griffin and Shannon[73] summarized the clinical role of HTO with knee ligament instability, showing the benefit of an anterior opening wedge HTO for severe recurvatum and correcting an abnormal increased tibial slope in select patients who had failed multiple ligament reconstructions.

Marti and coworkers[125] recommended that knees with ACL insufficiency and associated medial arthritis with a tibial slope of 10 degrees or more undergo correction at the time of a varus-producing osteotomy. However, no clinical data were provided to demonstrate whether a change in slope decreased instability symptoms. Other authors[54] have discussed increases in ACL tensile loads when tibial slope exceeded 10 degrees and postulated the need for correction, again without clinical data.

Griffin and Shannon[73] noted that the anterior tibial subluxation with ACL insufficiency results in a "copula" owing to increased damage of the medial plateau; however, the effect of a medial meniscectomy on producing the same effect should be considered.

We agree with recommendations to correct tibial slope when a distinct abnormality is present (Figs. 26-22 and 26-23). The published literature does not provide objective data regarding the degrees of abnormal increase or decrease in tibial slope when corrective osteotomy is indicated where there is an associated ACL or PCL insufficiency.

It is probable that a change in AP shear forces, cruciate tensile loads, and tibiofemoral contact under dynamic conditions would not have clinical significance after a 5-degree change in the tibial slope when the preoperative tibial slope is in the normal range. Therefore changing

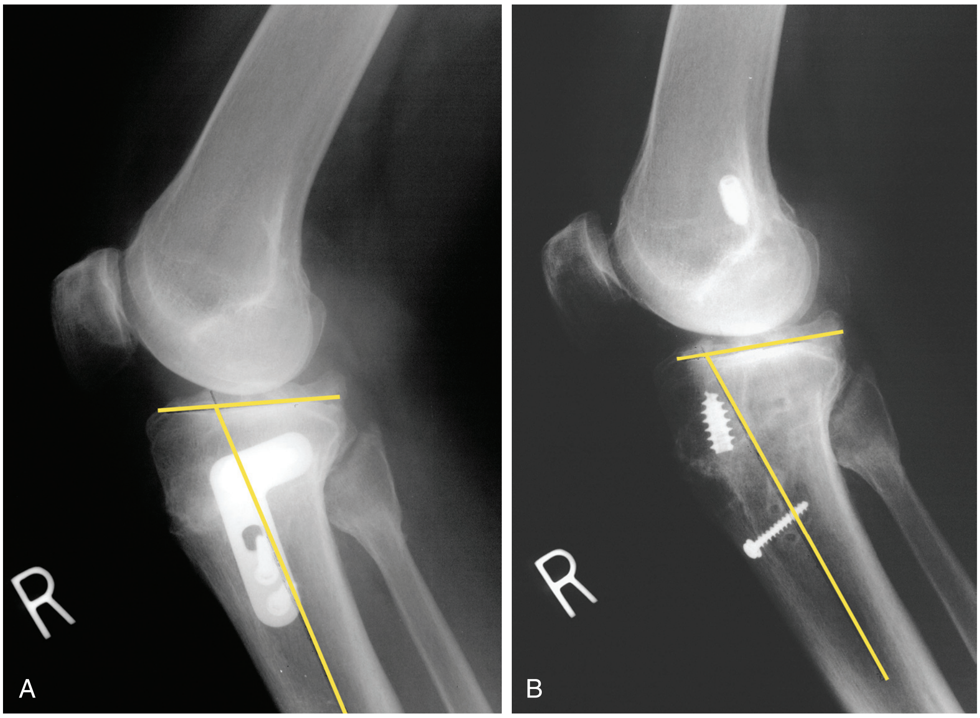

FIG 26-22 Radiographs of a 52-year-old physician referred for treatment after a closing wedge osteotomy (**A**) and subsequent anterior cruciate ligament (ACL) bone-patellar tendon-bone autograft (**B**) that failed. It would have been desirable to correct the abnormal tibial slope, which may have been a factor in the ACL graft failure.

Check the box that best describes the change you have had in sports activities since your injury or surgery. My sports activities have:

Not changed

☐ I have no/slight problems

☐ I have moderate/significant problems

Increased

☐ I have no/slight problems

☐ I have moderate/significant problems

Decreased

☐ I have no/slight problems

☐ I have moderate/significant problems

☐ For reasons not related to my knee

Stopped, given up all sports

☐ I have moderate/significant problems when I play sports

☐ For reasons not related to my knee

FIG 41-7 Change in sports activities.

Check the problems you have during:

1. Walking
check one box:
☐ Normal, unlimited (40)
☐ Some limitations (30)
☐ Only 3-4 blocks possible (20)
☐ Less than 1 block; cane, crutch (0)

2. Stairs
check one box:
☐ Normal, unlimited (40)
☐ Some limitations (30)
☐ Only 11-30 steps possible (20)
☐ Only 1-10 steps possible (0)

3. Squatting/kneeling
check one box:
☐ Normal, unlimited (40)
☐ Some limitations (30)
☐ Only 6-10 possible (20)
☐ Only 0-5 possible (0)

4. Straight running
check one box:
☐ Fully competitive (100)
☐ Some limitations, guarding (80)
☐ Definite limitations, 1/2 speed (60)
☐ Not able to do (40)

5. Jumping/landing
check one box:
☐ Fully competitive (100)
☐ Some limitations, guarding (80)
☐ Definite limitations, 1/2 speed (60)
☐ Not able to do (40)

6. Hard twists/cuts/pivots
check one box:
☐ Fully competitive (100)
☐ Some limitations, guarding (80)
☐ Definite limitations, 1/2 speed (60)
☐ Not able to do (40)

FIG 41-8 Activities of Daily Living and Sports Function Scales.

"Climbing" and "squatting" assess the ability of the knee to function under repetitive loading conditions. The factor "walking on uneven ground" is important for assessing joint instability in knees after a ligament injury or reconstruction. The factors "lifting/carrying" and "pounds carried" are helpful in assessing the general ability of the knee to tolerate specific loading conditions. The number of factors assessed was limited for the sake of brevity and simplicity, even though many others could have been included. These factors were not chosen to relate to one diagnosis or condition. Rather, they provide a general intensity rating of the work conditions on the lower extremity.

Each factor is graded according to one of two numeric scales: five factors are assigned a possible total of 10 points, and two factors are assigned a possible total of 5 points. In terms of rating loads placed on the knee joint, the numbers assigned to rate the work intensity of one factor do not necessarily equal the same numbers assigned to rate the work intensity of other factors. The actual loads placed on the knee joint are a function of multiple intrinsic and extrinsic factors that would require actual measurement. The scores for each factor are totaled, providing a numerical score for data reporting purposes. Occupations may then be categorized based on the total number of points as either disabled (0 points), very light (1-20 points), light (21-41 points), moderate (41-60 points), heavy (61-80 points), or very heavy (>80 points). The data may be expressed as means and SD for the population under study or through the distribution of patients in the six occupational categories before and after treatment.

The second major component in the assessment of work activities is the change that occurs in these activities between treatment periods, the most common occurring between preoperative and most recent follow-up evaluations. The format and terminology are the same as those used in the assessment of the change in sports activities between treatment periods, previously described in Figure 41-7. Importantly, the determination is made if changes in work activities are caused by knee-related or non–knee-related reasons and if patient is experiencing symptoms in her or his occupation.

The reliability of the Occupational Rating scale was demonstrated to be adequate in patients with ACL ruptures, chronic patellofemoral disorders, degenerative meniscal tears, and degenerative knee joint arthritis.[6] This scale is useful in the clinic to rate and categorize the occupational status of workers' compensation patients and in the