Anatomical Reconstruction of the Anterior Cruciate Ligament with a Patellar Tendon Autograft Using a Miniarthrotomy Technique

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Looking at the drawings in Hey Groves'[1] pioneering (1920) description of cruciate ligament reconstruction, it is obvious that what the author had in mind was insertion of the anterior cruciate ligament (ACL) at the anatomical attachment sites, even though he did not make that point in so many words. Palmer[2] was the first to stress the importance of precise drill-hole placement in 1938, and to design his own drill guide to obtain this precision. And only in the last 10 years have the biomechanical principles of accurate cruciate reconstruction been established. The term "isometry" was coined to express the need for a near-constant distance between the femoral and tibial attachments of the substitute ligament throughout the range of knee movement. In practice, however, ideal isometry is impossible to achieve, and length variations of up to 2 mm are often acceptable. Both the anterior and the posterior cruciate ligament are made up of several bundles, with each bundle consisting of a large number of fibrils (Figure 1a, b). There is no point in the range of movement, including full extension, at which all the ACL fibers would be taut; throughout the range, some fibers will be tense, while others will be slack.[3] The greater part of the stress is taken by the anteromedial bundle; these are the fibers that are tense in full extension.[3] This is why Friederich. et al.[3] recommend ACL reconstruction with drill holes within the proximal and distal attachments of the native anteromedial bundle. Hefzy, et al.[4] tried to determine the factors that affect the region of most isometric femoral attachments of the ACL. They noted that there is no completely isometric attachment. Kentsch and Muller[5] described for the first time a technique for replacing both the anteromedial and the posterolateral bundle using a split patellar tendon graft. One strip would be positioned over the top, the other through a transcondylar tunnel. However, this technique is very difficult and time-consuming.

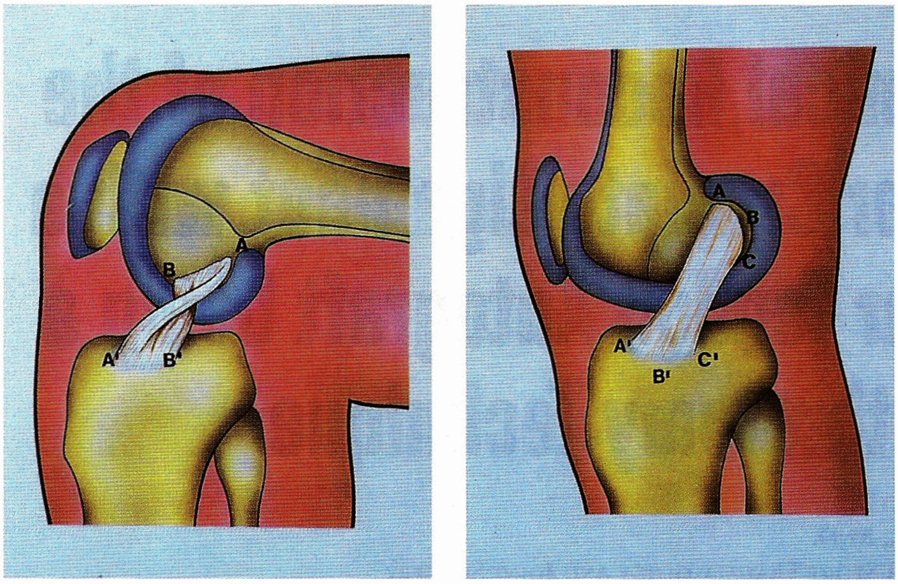

Figure 1a (left) and Figure 1b (right). Twisting of the ACL in flexion and extension. Anteromedial bundle AA'; posterolateral bundle BB' (Reprinted with permission: Girgis FG, Marshall JL, Monajem ARS: The cruciate ligaments of the knee joint. ClinOrthop 106:216-231,1975)

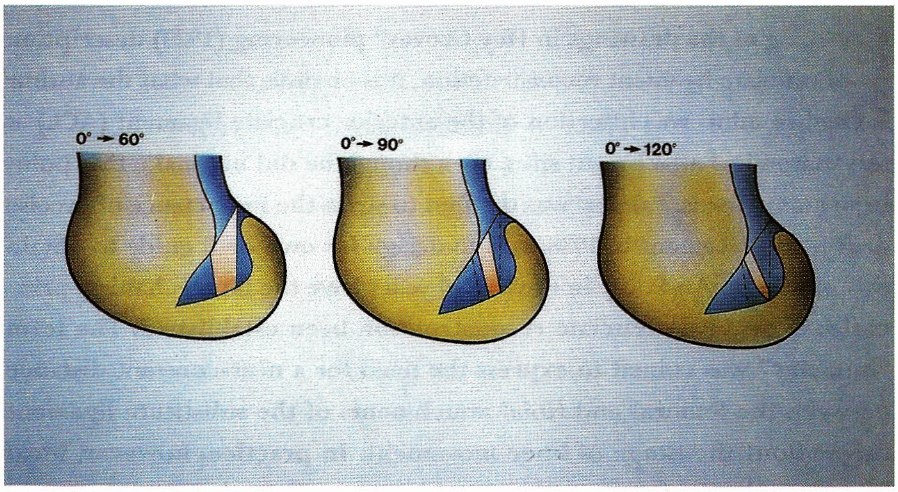

Figure 2. 2 mm region of the most isometric attachments of the ACL (Reprinted with permission: Hefzy MS, Grood ES, Noyes FR: Factors affecting the region of most isometric femoral attachments. Part II: The anterior cruciate ligament. Am J Sports Med 17:208-215, 1989). The long axis of this region corresponds to the long axis of the ACL attachment.

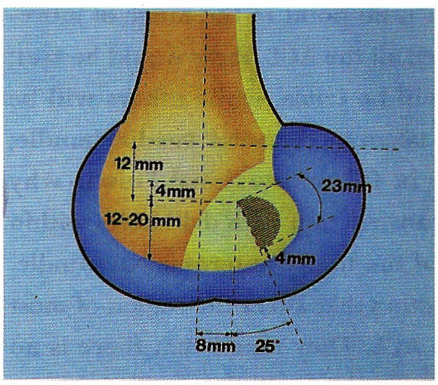

Figure 3. Femoral attachment of the ACL and dimensions (Reprinted with permission: Girgis FG, Marshall JL, Monajem ARS: The cruciate ligaments of the knee joint. Clin Orthop 106:216231, 1975)

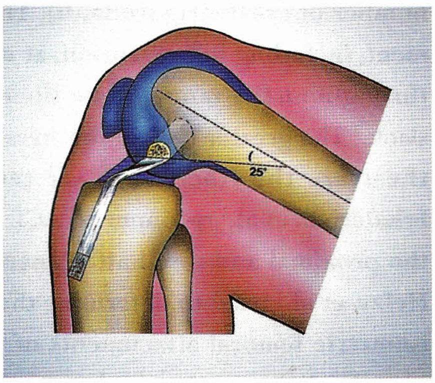

Figure 4. The bone plug has been impacted into the femoral tunnel in such as way as to place the transverse axis of its cortex in the 2 mm region described by Hefzy et al. At the tibial end, the graft has been pulled through the a.p. slot, with the anteromedial bundle facing forwards. With this pattern, the graft when twisted will behave like the native ACL.

Hefzy, et al.[4] found that the ACL fibers attached in a certain area (Figure 2) did not undergo more than 2mm change in length. The long diameter of this 2-mm region of most isometric attachments coincides with the anatomical longitudinal axis of the cruciate attachment, as determined by Girgis, et al.[6] and Odensten and Gillquist[7] (Figure 3). There is a distally open angle of 25 degrees between the long diameter of the 2-mm area and the long axis of the femoral shaft. From these findings, Hefzy, et al. conclude that where flat tendinous bands, such as the patellar tendon, are used for cruciate reconstruction, the anatomical axis of the bone block inserted into the femur should be rotated to make the transverse axis of its cortex coincide with the 2-mm region (Figure 4). The bone block should finish flush with the intercondylar wall to ensure that all the graft fibers will be within the theoretical region of most isometric attachments. On the tibial side, the graft should be rotated to produce an anteromedial and a posterolateral bundle. This can be achieved by orienting the graft in the anteroposterior direction at the tibial insertion site.

Anatomical reconstruction

In order to match the anatomical pattern as closely as possible, we have based our technique on the results of the experimental studies performed by Hefzy, et al.[4] For the femoral site, Hertel's press-fit technique[8] has been adopted. At the tibial end, the graft is placed in an a.p. slot rather than in a drill hole (Figure 5a,b). The operation can be performed as an arthroscopically-assisted procedure.

Open versus arthroscopic ACL reconstruction

We prefer open reconstruction via a miniarthrotomy, since the skin incision can be kept even shorter than that required for a wholly arthroscopic procedure. With an incision measuring only 4 cm in length, a newly developed retractor with fiber-optic illumination gives optimum exposure of the intercondylar notch and the femoral insertion site. In prospective studies,[9,10] wholly arthroscopic reconstruction was not found to be superior to miniarthrotomy surgery, and the technique had more disadvantages: (1). When performed by surgeons of roughly equal skill, open reconstruction requires on average 30 minutes less operative time.[10] (2) This significantly reduces the cost of the procedure; equally, there are savings in terms of lavage fluid, shavers, and repairs and replacements of damaged arthroscopes (3). (According to Shelbourne, et al., the savings amount to $1,800US.) Three-dimensional vision ensures greater accuracy; also, the technique takes less time to learn (4). There was no difference in analgesic intake, the in-patient stay, and rehabilitation time.

Timing of surgery

The immediate care of ACL injuries is increasingly being abandoned in favor of initially delayed (early secondary) reconstruction because of the rate of arthrofibrosis that is no longer considered acceptable.[11,12,13]

Instead of an immediate operation, the patient begins rehabilitation to prepare himself for the procedure. The aim is to recover free mobility and reduce the initial swelling. The combination of cryotherapy and compression treatment is the therapy of choice for the control of pain and swelling in the early phase. The Cryo/Cuff® system has proved to be very effective (Figure 14a, b) to cool and compress the knee; it is also easier for the patient to manipulate than ice bags and compression bandages.[14,15] The mobility of the knee is assessed as normal if the same degree of mobility is achieved as on the opposite knee. In addition, the patient should work on achieving a normal gait. Muscle-strength training begins as soon as he has free mobility and the pain has subsided. It is important that the tendency of the swelling to return is kept to a minimum with free mobility in the subsequent preoperative period.

Another important part of the preoperative phase is the patient's mental preparation.[16, 17] It begins immediately after the first pain has subsided. He is informed in detail about the reasons for delaying reconstruction. Delaying surgery until the inflammation is reduced and a normal, full range of motion is possible allows postoperative range of motion to be more predictably and quickly obtained. Most athletes who sustain an acute ACL tear undergo a series of mental changes during the early period after their injury. Depression, denial, and then ultimately acceptance of the injury can take weeks to occur. To operate on the patient during this transition makes postoperative rehabilitation difficult. Allowing the patient to overcome his initial fears of the injury and finally accept the upcoming surgery with a positive mental attitude has been found to allow the postoperative goals to be achieved sooner and more predictably.

The surgical operation and in particular the subsequent rehabilitation phase is explained in detail using models and a teaching video recorded especially for cruciate ligament patients. It is important for the patient to be precisely aware of the objectives of rehabilitation.

The importance of a positive mental attitude should not be underestimated. Patients who have the feeling that they can control the situation themselves appear, from our observations, to complete rehabilitation with significantly fewer complications and with greater success. When planning the timing of the operation, considerations must be given to school, work, and family obligations. It is explained to the patient that he is not losing any time before he can resume his former employment and sporting activity. In the case of younger school pupils, we usually wait for the long holidays, and in the case of older students, we wait for the end of term before the operation so they can concentrate on the rehabilitation without distraction.

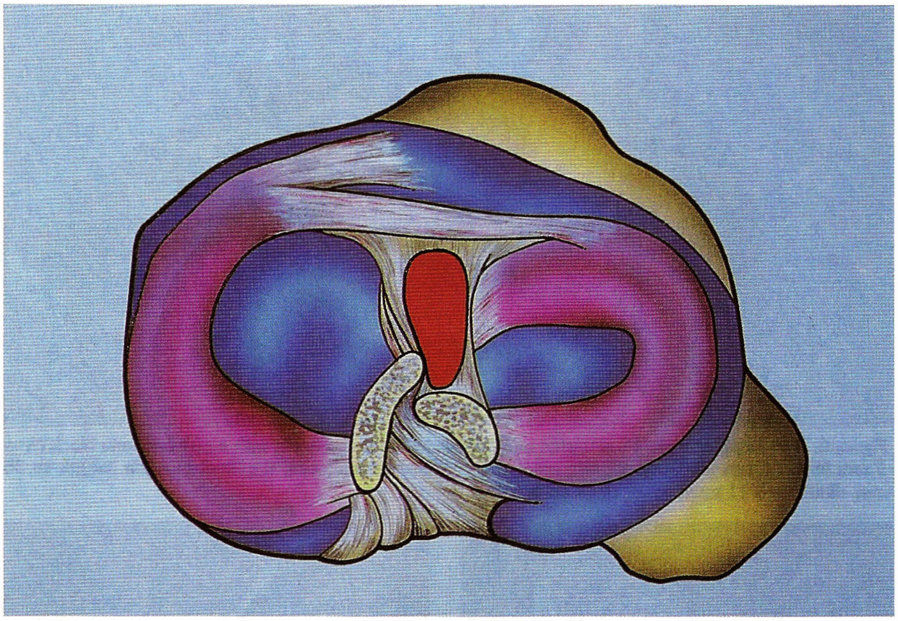

Figure 5a. Tibial attachment of the ACL.

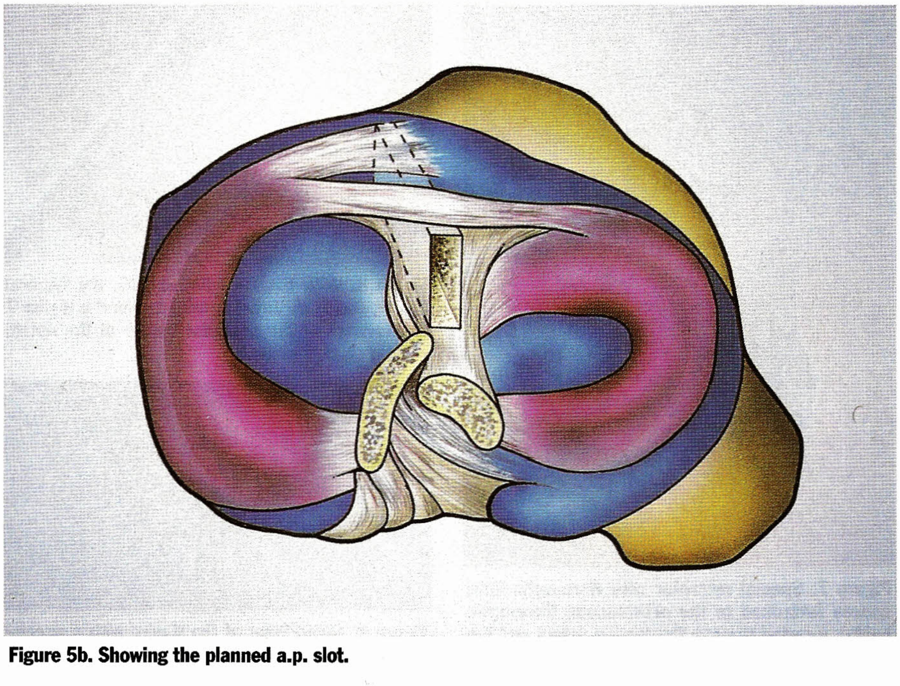

Figure 5b. Showing the planned a.p. slot.

Surgical technique

The patient is positioned with his leg hanging over the edge of the table, without a special leg holder. The surgeon sits facing the patient's knee. Surgery is routinely preceded by arthroscopy, to detect and treat any associated conditions (such as division of the infrapatellar fold, to facilitate the subsequent use of the retractor; meniscal resection/repair; microfracturing in Grade IV cartilage lesions).

For the harvesting of the graft, a 4 cm medial parapatellar incision is made, starting at the tibial tubercle and running proximally. Thanks to the great mobility of the skin in this region, there is no need for a longer incision. The sheath of the patellar tendon is divided lengthwise and dissected off. A 10-to-11 mm wide strip (measured at the center of the tendon) is raised in the mid-portion of the patellar tendon. Using a 2-mm drill, one hole each is drilled in the central part of the patellar and the tibial bone block. Next, an oscillating saw is used to cut a bone block (20-mm long, 12-mm wide, 5–6 mm thick) from the patella (Figure 6); this block will later be pulled through the 6-mm-wide slot in the tibia. If, on removal, its thickness exceeds 6 mm, it should be trimmed to size with the oscillating saw; the trimmings will be replaced in the patellar defect at the end of the procedure. At the tibial tubercle, a bone block (30–35 mm long and 9–11 mm wide) is sawn out. The block is trimmed to form a cylindrical plug, using nibblers and an oscillating saw. Holding sutures (Mersilene 3 to 5) are drawn through the drill holes. The graft is kept wrapped in pads which are soaked in Ringer's solution, awaiting implantation.

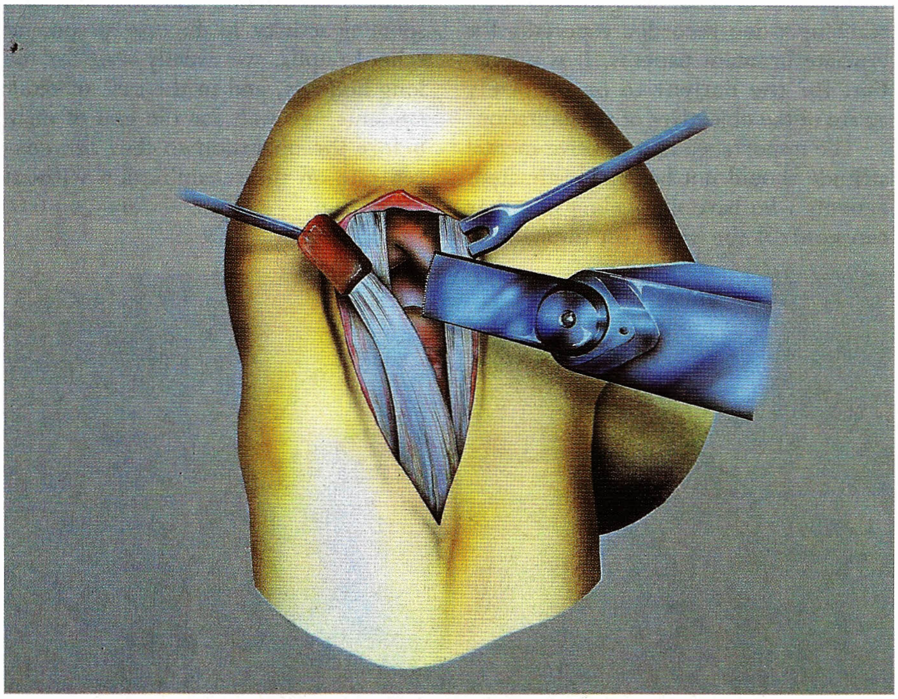

Figure 6. Harvesting of a ca. 11 mm wide mid-third patellar tendon graft; with a patellar bone block circa 5 mm high, 25 mm long, and 12 mm wide; and a cylindrical plug from the tibial tubercle (length ca 35 mm, diameter 9-11 mm); using an oscillating saw.

The joint is opened through the tendon defect and the fat pad. A special retractor with a fiberoptic light source (attached to the arthroscope fiberoptic cable), is inserted through the tendon defect and the fat pad (Figure 7). It permits an excellent illumination of the notch. Any portions of the fat pad that interfere with the surgeon's view of the field are resected. Careful and thorough notch debridement is performed. Special rasps are used to enlarge the notch; larger osteophytes are removed with a chisel. Next, the femoral tunnel is prepared. Remnants of the ACL are identified at the femoral attachment site. A newly developed femoral aiming device (Arthrex, Naples, Florida) permits the accurate placing of a 2-mm K-wire 7 mm from the posterior border of the notch, at 11 o'clock/1 o'clock positions (Figure 8). The K-wire is drilled through the femoral condyle to run obliquely from anteromedial to posterolateral, until it protrudes through the skin of the thigh. Special atraumatic reamers (Figure 9), which come in sizes from 8 to 12 mm (increasing by 0.5 mm increments), are used to drill over the K-wire to the measured diameter of the cylindrical tibial bone plug. Initially, only the medial cortex is pierced. Subsequently, reaming is done with a 1-mm smaller bit, piercing the lateral cortex as well. In this way, the bony bed is

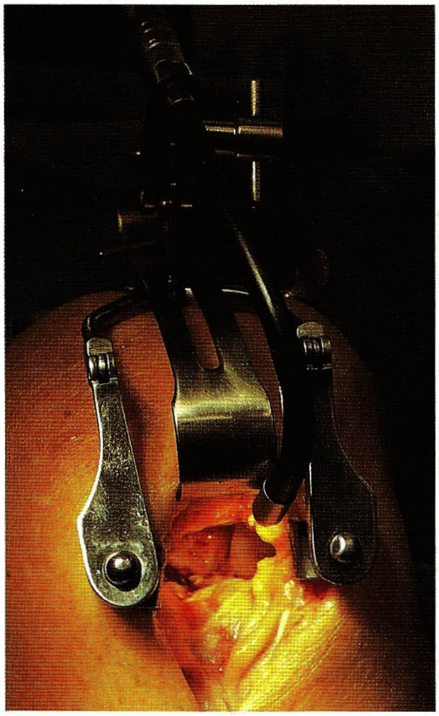

Figure 7. Special retractor with fibre-optic light source (attached to the arthroscope fibre-optic cable), inserted through the tendon defect and the fat pad.

Figure 8. With the knee flexed 115, the femoral aiming device (Arthrex) is used to insert a K-wire 7 mm forward of the posterior border of the notch, at 11 o'clock/1 o'clock.

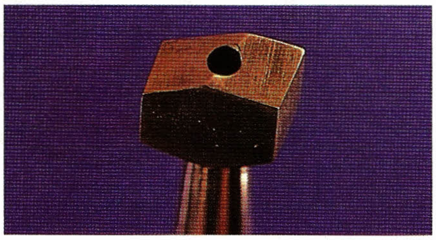

Figure 9. Overdrilling of the K-wire with a special atraumatic reamer.

prepared for the pressfitting of the bone plug. A looped suture to permit the bone plug to be pulled through at a later stage is taken out through the skin with the K-wire.

The medial aspect of the head of the tibia is freed from soft tissues to the pes anserinus. A 6-mm gouge is used to fashion a longitudinal groove in the tibial head, to mark what will be the exit of the tibial slot. After the removal of the cortex, the cancellous bone at the site of the intended slot is gouged out, and preserved together with the excess cancellous bone obtained from the tibial tubercle plug. A drill hole is made in the area of the tibial ACL attachment, using a 6-mm drill. The drill is moved to and fro in the a.p. direction, to fashion a slot. This slot is given its definitive size with a 6-mm rasp (Figure 10). The arthroscope is advanced through the slot into the joint. With the knee fully extended, a check can be made to see whether the slot is sufficiently posterior (posterior border approximately 2–3 mm in front of the PCL). The posterior edge of the slot in the tibial plateau is champered with a curette.

The sutures attached to the tibial tubercle plug of the graft are placed into the loop that was previously passed through the femoral drill hole, so that they can be pulled through to the outside. The plug is mounted on a special impactor fitted with 2 spikes. With the knee in 120° flexion, the plug to bring its cortex to lie parallel to and facing the tibial plateau. Thus the angle between the cortex and long axis of the femur is approximately 25°. With strong traction on the sutures from outside, the plug is driven in with the impactor to finish flush with the lateral wall of the intercondylar fossa (Figure 11a, b).

In very rare cases (faulty measurements; osteoporotic bone), an interference screw will need to be inserted to provide supplementary femoral-plug fixation. During the impaction of the femoral plug, a K-wire is passed from the front through the drill hole, to exit through a lateral stab incision. A special cannulated cancellous screw is passed through this incision and inserted over the K-wire. Whereas, with conventional techniques, the interference screw is usually inserted from the front, the method described here has the advantage of keeping the metal out of the joint.

The patellar part of the graft is twisted to make the graft fibers facing the PCL to lie anteriorly, so as to produce an anteromedial and a posterolateral bundle. Once this has been achieved, the bone block is pulled through the slot. Isometry is tested. At full flexion and extension, the maximum play of the block in the tibial slot should be 2 mm; with hyperextension, the substitute ligament should be tense, and the bone block should be pulled into the slot. In this position, a check is also made to ensure that there is sufficient clearance between the graft and the anterior border of the notch. Since the graft is likely to hypertrophy, this clearance should not be less than 2 to 3 mm (negative impingement test). Next, in full extension, a tensiometer is attached to the bone-block sutures, to apply 100 N pretension to the ligament. According to Woo (personal communication), the tension of the human anteromedial bundle in full extension is circa 70 N. Since the expected drop in tension following graft fixation is circa 30 percent,[18] a pretension of 100 N should be the right order magnitude. The bone block is then fixed by means of a 1.6-mm K-wire that is driven from medial to lateral through the head of the tibia, passing across the bone block (Figures 12 and 13). The end of the K-wire is bent to prevent migration. Unlike interference screws, the method

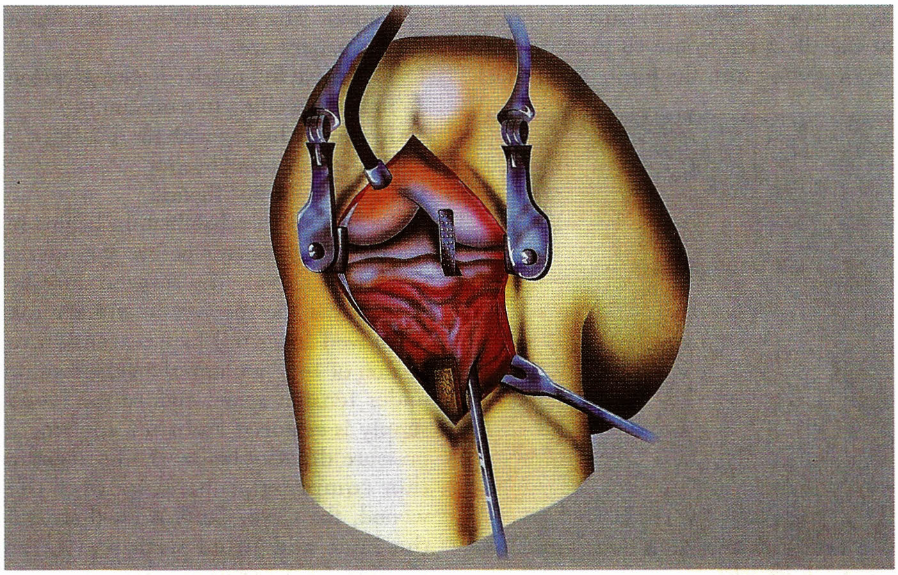

Figure 10. The rasp is moved forwards and backwards to fashion the tibial slot.

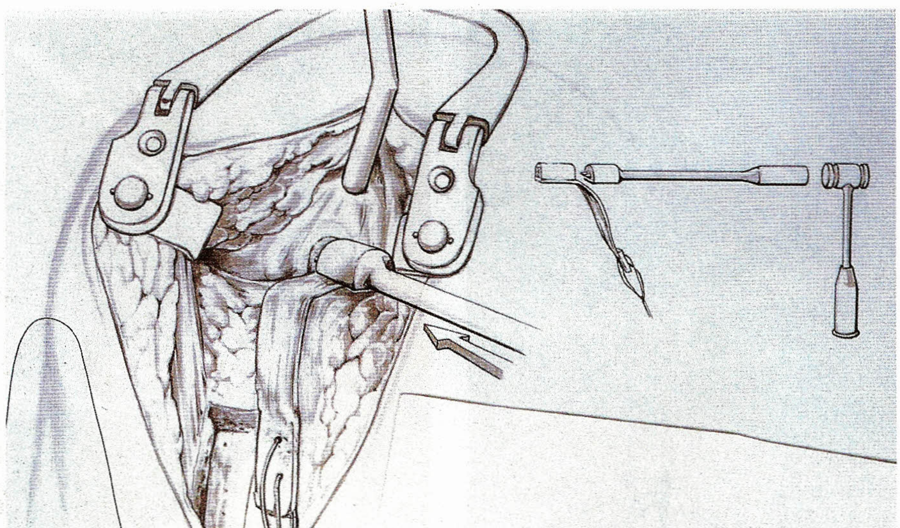

Figure 11a. With the knee flexed approximately 115°, a special impactor (I I b) is used to impact the cylindrical plug from the tibial tubercle into the femoral tunnel, in such a way as to place the bone plug cortex parallel to the tibial plateau. In his way, the transverse axis of the graft will coincide with the transverse axis of the previous anatomical attachment of the ACL (distal open 25° angle with the long axis of

of fixation described here has the advantage of allowing defined graft pretensioning. Also, its pullout strength is greater than that of parallel interference screws, and it is 200 times less expensive.

In some cases (e.g., with patella alta), the tibial slot may be too short, leaving the bone block standing proud. In this case, the slot may be lengthened distally as required.

An immediate test is made for full extension and a Lachman test is performed. The result of the latter should be approximately 2 mm, as on the opposite knee. Finally, the cancellous bone removed earlier is placed in the tibial tunnel in front of the graft and the bone block. Finger pressure is applied at the tibial entry site to prevent chips from getting into the joint. The cancellous bone is firmly impacted to ensure sound integration and to prevent graft movement.

Figure 11b. Impactor.

The patellar tendon defect is closed by apposing the edges of the uppermost layer with a continuous Vicryl suture. Another continuous Vicryl suture is used to close the retinaculum and the tendon sheath. Finally, 10 ml bupivacaine 0.5 percent with adrenaline and 1 amp of morphine are injected into the joint, and the extra-articular field is infiltrated with 10 ml bupivacaine 0.5 percent with adrenaline.

Postoperative management

The immediate postoperative phase of rehabilitation includes the day of the operation. The objectives of this phase for the patient are:

1. To achieve full passive hyperextension
2. To keep swelling to a minimum
3. To control his leg with his muscles
4. To secure wound healing
5. To strive for 90° flexion

Postoperative rehabilitation begins in the operating theater before the operation site is closed. The surgeon must be certain that the reconstructed knee can be moved from full hyperextension to flexion of 145° without the graft coming under tension again. Before the blood supply is restored and after applying a pressure dressing below the knee and a thin compression bandage over the wound, the Cryo/Cuff® is fixed around the knee and filled with ice water (Figure 14a) (pressure 30 cm water gauge). Finally, a removable splint is applied in extension.

Passive-motion therapy on the motion machine is started on the knee joint affected within the pain-free range. The patient is allowed to get up to go to the toilet and to eat meals, putting as much weight on the leg as is tolerable using forearm crutches. Otherwise, he should stay in bed for the first few days after the operation, with his leg raised (with the foot of the bed elevated) and with continuous cooling as described above (Figure 14b). The full passive extension of the knee joint should be practiced regularly for 10 minutes each waking hour by placing the foot in bed on one or two pillows so that the knee joint is unsupported.

The extended leg should be raised at an early stage in order to activate the quadriceps while simultaneously tensioning the muscles (co-activation), and this should be possible immediately after surgery. The activation of the quadriceps mobilizes the patella and stretches the patellar tendon, thus preventing a patella baja, or what is known as patella entrapment syndrome. Exercises are also performed using a StairMaster®, leg press, etc. Aquajogging is also suitable for early rehabilitation (after the first week).

From the fifth week on, if the patient has achieved the goals of 1) full extension, 2) minimal swelling, 3) near full flexion, and 4) 65 percent or greater strength, we have found that returning

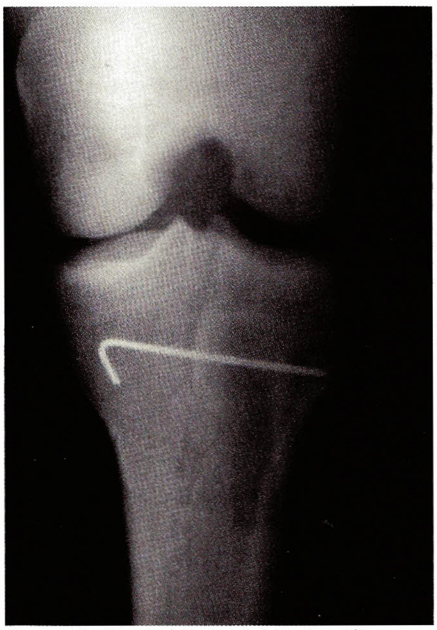

Figure 13. Check radiograph following ACL reconstruction.

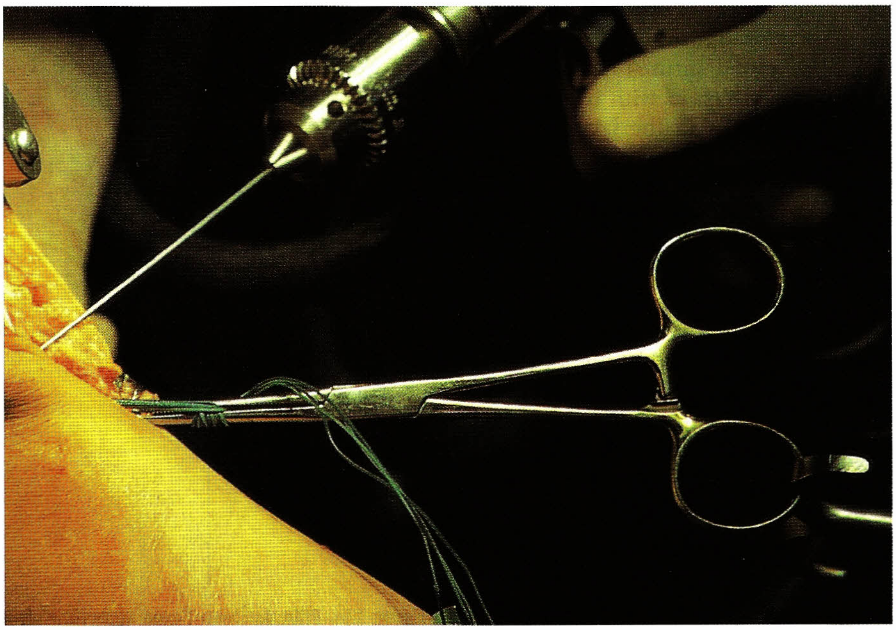

Figure 12. Pretensioning of the distal bone block using a tensiometer; and fixation by means of a K-wire inserted across the bone from medial to lateral.

to full sporting activities can be allowed without a fear of losing graft integrity.

The patient is allowed to increase his activity level as long as he monitors any swelling and decreased motion (especially full extension) and as long as he demonstrates a continued increase in leg strength and functional ability.

We have found that it takes 3 to 4 months of this increased activity until the patient feels comfortable enough to return to full unrestricted athletic activity.

Clinical experience

Since 1990, we have used the technique described in more than 1,700 ACL reconstructions. During the critical first year, early failure occurred in 31 cases (1.8 percent). Most of these were cases of combined and pronounced instabilities, where no additional stabilization had been performed. Two of these patients underwent repeat reconstruction, at 11 and 14 months, respectively, using a graft harvested from the contralateral side. As a result of the use of the Cryo/Cuff®, and thanks to the intra-articular administration of morphine and bupivacaine during surgery, no additional analgesics were needed in 27 percent of the cases; standard non-opiate oral analgesics were required in 67 percent; while 6 percent of patients needed parenteral opioids. Two prospective studies (15 and 19) have shown a significant reduction in the need for analgesics where the Cryo/Cuff® was used. Early postoperative complications were confined to painful transient haematomas, mainly of the calf and the tibia (23 percent), associated with early mobilization. There were no deep infections. Deep-vein thrombosis occurred in 1.6 percent of the cases; there were no clinically demonstrable embolisms. Twenty-three percent of the patients complained of pain at the graft harvesting site; in most of these cases, the pain had subsided by the sixth month. This tallies with the findings of Rubinstein, et al.[19] Secondary-extension lag as a result of cyclops lesions[20] were observed in 1.8% of the cases. All these lesions were managed by arthroscopic surgery, with no further problems being encountered. Infrapatellar contracture syndrome (patellar entrapment)[21] was not observed in this series. We feel that this was attributable to preoperative and accelerated postoperative rehabilitation. STI

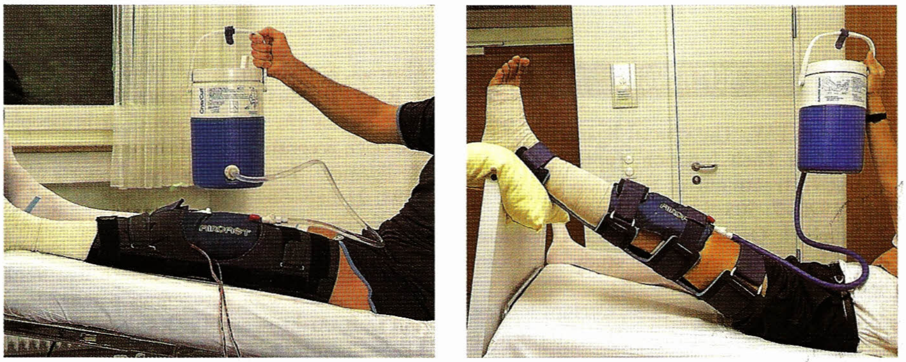

Figure 14a (left) and Figure 14b (right). Postoperative positioning of lower limb in a hyperextension splint with a Cryo/Cuff® (Aircast).

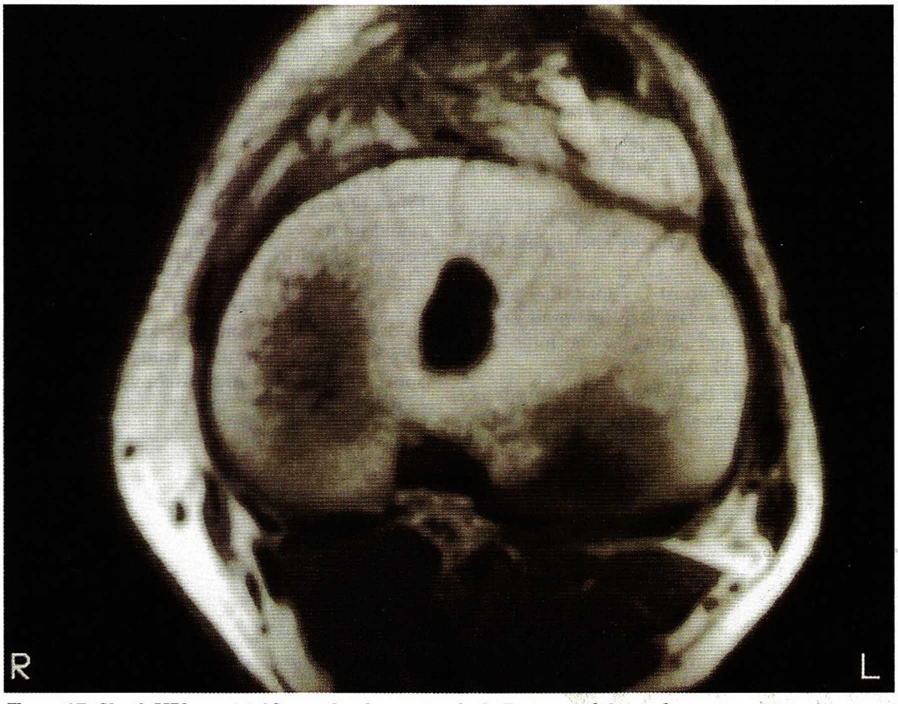

Figure 15. Check MRI scan at 12 mo, showing anatomical alignment of the graft.

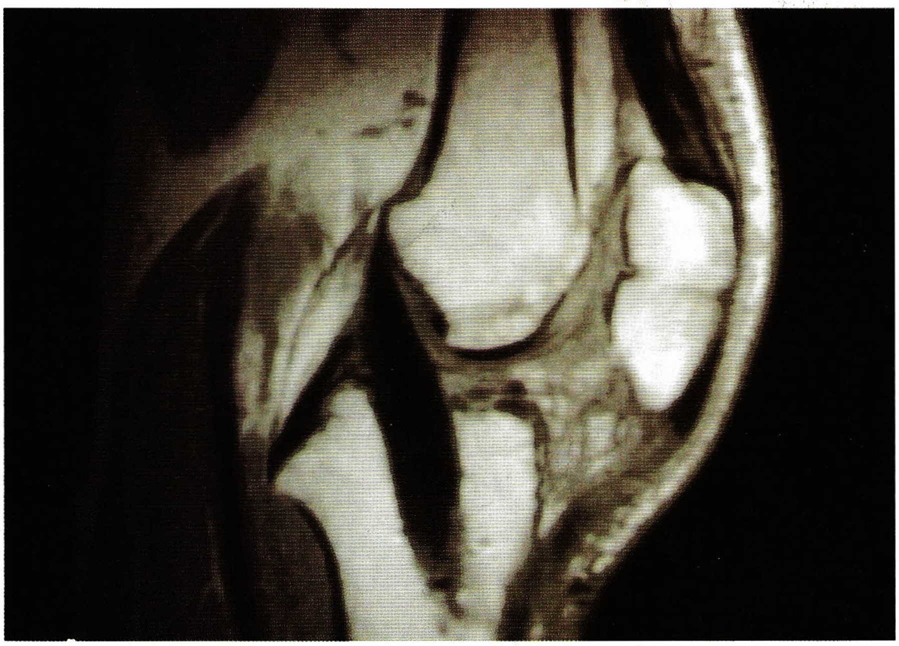

Figure 16. Axial MRI scan in the same patient, showing a.p. graft alignment, with formation of an antero-medial and a posterolateral bundle.

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