TIMO JÄRVELÄ

Anterior Cruciate Ligament Reconstruction with a Bone-Patellar Tendon-Bone Autograft

A Five- to Nine-Year Follow-up of 101 Patients

ACADEMIC DISSERTATION
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the Faculty of Medicine of the University of Tampere,
for public discussion in the small auditorium of Building K,
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Teiskontie 35, Tampere, on May 23th, 2001, at 12 o'clock.

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To my children
Marika and Santeri
and to my loving wife
Kati

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1. LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, referred to as I - V in the text:

I T. Järvelä, M. Nyyssönen, P. Kannus, T. Paakkala, M. Järvinen: Bone-patellar tendon-bone reconstruction of the anterior cruciate ligament. A long-term comparison of early and late repair. Int Orthop (SICOT) 1999: 23: 227-231.

II T. Järvelä, P. Kannus, M. Järvinen: Anterior knee pain 7 years after an anterior cruciate ligament reconstruction with a bone-patellar tendon-bone autograft. Scand J Med Sci Sports 2000: 10: 221-227.

III Timo Järvelä, Timo Paakkala, Pekka Kannus, Markku Järvinen: The incidence of patellofemoral osteoarthritis and associated findings 7 years after anterior cruciate ligament reconstruction with a bone-patellar tendon-bone autograft. Am J Sports Med 2001: 29: 18-24.

IV Timo Järvelä, Timo Paakkala, Kati Järvelä, Pekka Kannus, Markku Järvinen: Graft placement after the anterior cruciate ligament reconstruction. A new method to evaluate the femoral and tibial placements of the graft. Knee 2001 (accepted).

V Timo Järvelä, Pekka Kannus, Markku Järvinen: Anterior cruciate ligament reconstruction in patients with or without accompanying injuries. A reexamination of the subjects five- to nine- years after the reconstruction. Arthroscopy 2001 (accepted).

2. ABBREVIATIONS

ACL	Anterior cruciate ligament
ANOVA	Analysis of variance
AO	Arbeitsgemeinschaft für Osteosynthesefragen
AOSSM	American Orthopedic Society of Sports Medicine
BTB	Bone-patellar tendon-bone
ESSKA	European Society of Sports Traumatology, Knee Surgery and Arthroscopy
IKDC	International Knee Documentation Committee
LCL	Lateral collateral ligament
MCL	Medial collateral ligament
MRI	Magnetic resonance imaging
NS	Not significant
PCL	Posterior cruciate ligament
ROM	Range of motion
STG	Semitendinosus and gracilis tendons
SD	Standard deviation

3. INTRODUCTION

The anterior cruciate ligament (ACL) is the weaker of the two cruciate ligaments, and therefore maybe it torns easier than the posterior cruciate ligament (PCL) (Moore 1985). The knee joint becomes very unstable when the ACL is torn, because the ACL is crucial ligament in stabilizing the knee joint (Clancy and Smith 1991, Johnson et al. 1992).

The logical aims of the treatment of a torn ACL are to obtain a stable and painless knee joint with full range of motion and good muscle strength. Conservative treatment of a torn ACL often fails leading to chronic instability, muscle weakness, and post-traumatic osteoarthritis (Järvinen et al. 1991, Kannus and Järvinen 1987, Odensten et al. 1985). Primary suture of a torn ACL usually leads to late instability, too (Aho et al. 1986, Andersson et al. 1989, Clancy et al. 1988). Therefore, reconstruction of a torn ACL with an intra-articular autograft has become the most common method in ACL surgery (Fu and Schulte 1996). Among this catecory, the bone-patellar tendon-bone (BTB) autograft was considered the gold standard procedure in 1990s (Fu and Schulte 1996, Järvinen et al. 1995, Renström 1991, Shelbourne and Gray 1997). However, anterior knee pain and patellofemoral problems are often associated with this procedure (Rosenberg et al. 1992), although some studies have shown that these problems are also present with other procedure of ACL reconstruction (Aglietti et al. 1993, Aglietti et al. 1994). Recently, attention has moved towards the use of the semitendinosus and gracilis (STG) autograft with its relatively low donor-site morbidity (Corry et al. 1999). In fact, the most common current graft choices for the ACL reconstruction are the BTB and STG autografts (Fu et al. 1999), and that is why many experts see that the one golden standard procedure (BTB autograft) does not exist anymore in the ACL surgery.

The purpose of this study series was to assess the long-term results of the ACL reconstruction with a BTB autograft with special emphasis on the timing of the reconstruction and postoperative problems, such as anterior knee pain and patellofemoral osteoarthritis. We also developed a new method to evaluate the graft placement. In addition, we compared the long-term results of the reconstruction in patients with isolated tear of the ACL to those with an ACL rupture with accompanying injuries.

4. REVIEW OF THE LITERATURE

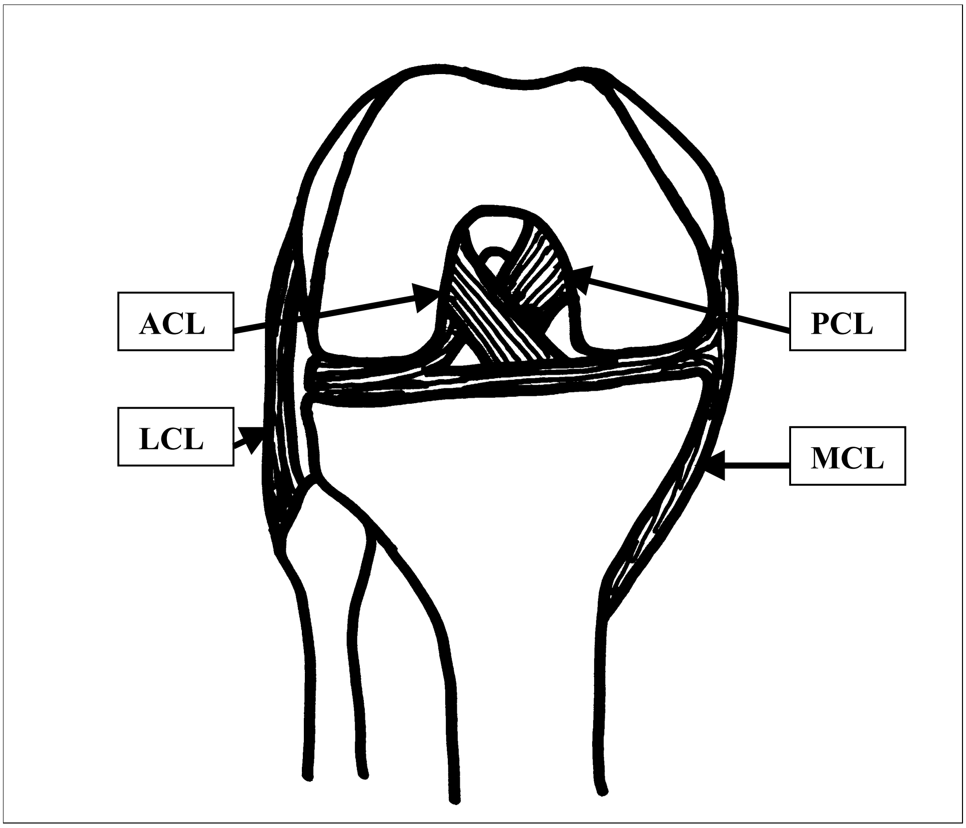
4.1. Anatomical considerations of knee ligaments and menisci

The ACL arises from the anterior part of the intercondylar area of the tibia, just posterior to the attachment of the medial meniscus. It extends superiorly, posteriorly, and laterally to attach to the posterior part of the medial side of the lateral condyle of the femur (Moore 1985) (Figure I). The ACL has two bundles; the anteromedial bundle and the posterolateral bundle. The fiber bundles of the ACL are under variable stress during knee motion. For example, the anteromedial bundle of the ACL experiences higher stress during flexion, and the posterolateral bundle experiences higher stress during extension (Fu et al. 1999). The ACL prevents posterior displacement of the femur on the tibia (or vice versa) and hyperextension of the knee joint. When the knee joint is flexed to a right angle, the tibia cannot be pulled anteriorly because it is held in place by the ACL.

The PCL arises from the posterior part of the intercondylar area of the tibia and passes superiorly and anteriorly on the medial side of the ACL to attach to the anterior part of the lateral surface of the medial condyle of the femur (Moore 1985). The PCL also has two bundles; the anterolateral bundle and the posteromedial bundle. The femoral attachment of the PCL is quite large (3 cm) because of the different directions of these two bundles on the femoral side. The anterolateral bundle is stronger of these two bundles, and it is tight in flexion. The posteromedial bundle is tight in full extension. The PCL is stronger than ACL. The PCL prevents anterior displacement of the femur on the tibia or posterior displacement of the tibia on the femur.

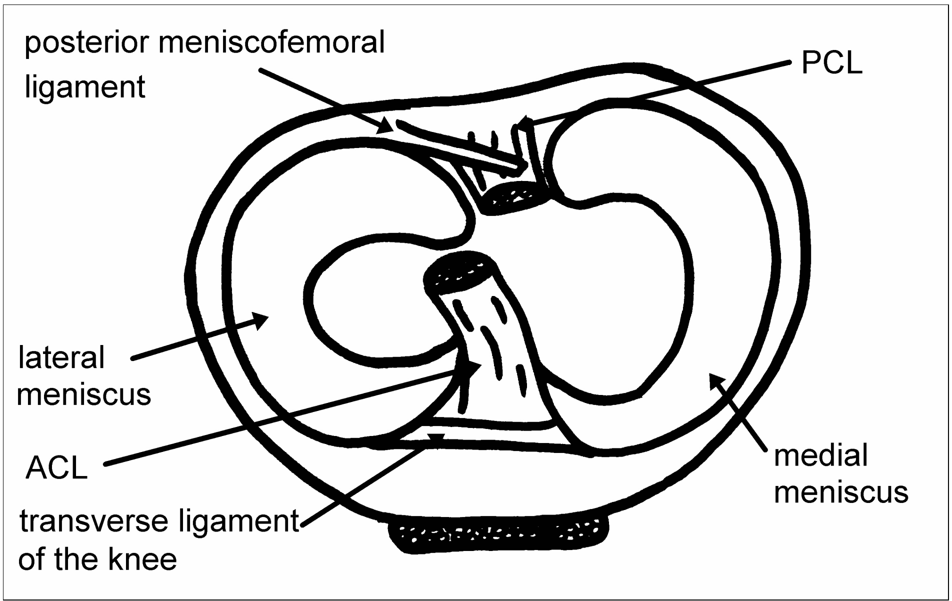
The medial collateral ligament (MCL) is a strong, flat band which extends from the medial epicondyle of the femur to the medial condyle and superior part of the medial surface of the tibia. The deep fibers of the MCL are firmly attached to the medial meniscus and the fibrous capsule of the knee joint. The lateral collateral ligament (LCL) is a round, pencil-like cord. It extends inferiorly from the lateral epicondyle of the femur to the lateral surface of the head of the fibula. The LCL is not attached to the lateral meniscus. The LCL is not commonly torn because it is very strong (Moore 1985) and because varus distortions of the knee are less common than valgus distortions.

Figure I. Anterior view of the right knee joint in knee flexion. ACL = anterior cruciate ligament, PCL = posterior cruciate ligament, LCL = lateral collateral ligament, MCL = medial collateral ligament.



The medial and lateral menisci are crescentic plates of fibrocartilage that lie on the articular surface of the tibia (Figure II). They act like shock absorbes. The lateral meniscus covers a larger area of articular surface than does the medial meniscus. The transverse ligament of the knee joins the anterior parts of the two menisci. This connection allows them to move together during movements of the femur on the tibia. The thickness of the transverse ligament varies in different people; sometimes it is absent (Moore 1985). The posterior meniscofemoral ligament arises from the posterior horn of the lateral meniscus posteriorly of the PCL to the lateral surface of the medial condyle of the femur (Netter 1991).

Figure II. Superior view of the tibial plateau and menisci.



4.2. Biomechanics of knee joint

The knee joint itself is both a hinge and a pivot joint. It is capable of movement in six degrees of freedom: three rotations and three translations (Woo et al. 1999). The description of knee motion can be accomplished by relating movement to three principle axes: the tibial shaft axis, the epicondylar axis, and the anteroposterior axis, which is perpendicular to the other axes. Translations along these axes are referred to as proximal-distal, medial-lateral, and anterior-posterior translation, respectively. Rotations about these axes are referred as internal-external rotation, flexion-extension, and varus-valgus rotation, respectively (Woo et al. 1999).

During the first 20 degrees of flexion, the movement is a rocking type of motion. In this extended position, tautness of ligaments prevents rotatory motion. After 20 degrees of flexion, the movement is a gliding type of motion, and relaxation of supporting ligaments also permit axial rotation. Since the axis of rotation is shifted toward the medial side, the extent of rotatory movements are greater on the lateral side (Turek 1984).

The stability of the knee joint depends upon the strength of the surrounding muscles and ligaments. The most important muscle in stabilizing the knee joint is the quadriceps femoris, particularly the inferior fibers of the vastus medialis and vastus lateralis (Moore 1985), and the most important ligament in stabilizing the knee joint is the ACL (Clancy and Smith 1991, Johnson et al. 1992). The ACL and the quadriceps femoris muscle are, in turn, mechanical antagonists (Hogervorst and Brand 1998).

Studies performed on young human cadaveric knees have shown the ultimate tensile load and stiffness of the human femur-ACL-tibia complex to be an average 2160 N (SD 157 N) and 242 N/mm (SD 28 N/mm), respectively (Woo et al. 1991). These values were upwards of three times as high as those for older specimens. The properties obtained for femur-ACL-tibia complexes from young donors should be used as the strength requirements for ACL grafts used for reconstructions (Woo et al. 1999).

4.3. Mechanism of injury

The relatively weak ACL is sometimes torn when the medial collateral ligament (MCL) ruptures after the knee is hit hard from the lateral side while the foot is on the ground (Moore 1985). First the MCL ruptures, opening the knee joint on the medial side. This may tear the medial meniscus and the ACL (external rotation and valgus stress). The ACL may also be torn when the tibia is driven anteriorly on the femur, the femur is driven posteriorly on the tibia, and the knee joint is severely hyperextended (anterior drawer manouver). The result is an isolated ACL rupture, which can also result in an injury of the flexion-internal rotation of the knee (Järvinen et al.1994).

The traumatic dislocation of the knee joint is not common (Moore 1985). However, this injury may occur, e.g., during an automobile or motorcycle accident. In addition to disruption of the ligaments of the knee (ACL, PCL, MCL and LCL), the popliteal artery, tibial nerve, popliteus, and biceps tendons may be injured in complete knee dislocation.

4.4. Clinical and radiological examination

In an acute phase of knee injury, it is rather difficult for an unexperienced physician to make the definitive anatomical diagnosis of the trauma (Mitchell 1999). However, it is important to identify those who need a specialist orthopedic opinion either immediately or later. Inability to bear weight, impaired range of motion, bruising, localised bony tenderness, and development of a hemarthrosis have been shown to correlate well with significant injury to the knee such as fracture, or ligament or meniscus damage (Bauer et al. 1995, Swensen and Harner 1995).

Many clinical tests are available for ACL insufficiency. The most common tests are the anterior drawer test, the Lachman test (Torg et al. 1976), and the Pivot shift test (Galway et al. 1972). Without anesthesia, accurate diagnosis of an ACL injury using these clinical tests is difficult in painful conditions. Therefore, it is important to reexamine the patient a few days or one week after the injury, and repeat these tests. The Lachman test seems to be the most accurate clinical test for chronic injury of the ACL (Kim and Kim 1995). The pivot shift test, which is highly sensitive and specific test for an ACL insufficiency, may yield a false negative result.

AP and lateral radiographs of the injured knee should be taken routinely after every significant knee injury, because these radiographs will show, if there is a fracture of the injured knee. However, if the anatomical diagnosis remains still unclear, magnetic resonance imaging (MRI) can help for correct diagnosis. MRI is at least as accurate as physical examination for diagnosing isolated ACL tears (Lee et al. 1988), although in knees with multiple ligament injuries, the diagnostic specificity of MRI for ligament tears decreases, as does the sensitivity for medial meniscal tears (Rubin et al. 1998).

4.5. Conservative treatment and primary suturation

In a long-term follow-up of patients with a complete ACL rupture, conservative treatment often fails leading to chronic instability, muscle weakness, and post-traumatic osteoarthritis (Järvinen et al. 1991, Kannus and Järvinen 1987, Odensten et al. 1985). Also, primary suture of a torn ACL is often followed by late instability (Aho et al. 1986, Andersson et al. 1989, Clancy et al. 1988).

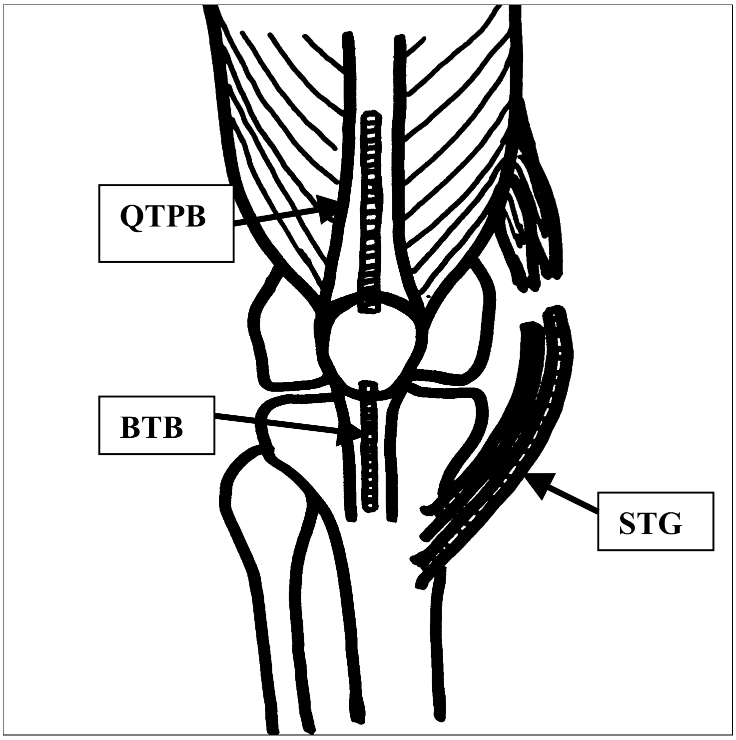
On the other hand, some studies indicate that patients who have no sport or other heavy physical activities can have acceptable functional results after non-operative treatment of an

ACL injury (Casteleyn and Handelberg 1996). However, patients without interest in sports activities are not the same group as all middle-aged or older patients. Older patients can also have sports activities such as skiing, tennis, and jogging, and after reconstruction of the torn ACL, these patients are often very pleased with the result (Plancher et al. 1998). In fact, their results can be successful and satisfying to a degree similar to that in younger patients (Heier et al. 1997). However, the result is good only if the patient is motivated to get back to sports activities.

4.6. Current graft options in ACL reconstruction

Currently recommended graft choices for ACL reconstruction include biologic autograft and allograft materials. Prosthetic ligaments are not recommended for the reconstruction of the ACL, because their failure rate is too high (between 40% and 78%) (Frank and Jackson 1997). Autograft choices include bone-patellar tendon-bone (BTB), quadrupled semitendinosus-gracilis tendon (STG), or bone-quadriceps tendon autografts (Figure III) (Fu et al. 2000). Allograft options include Achilles tendon, bone-patellar tendon-bone, and hamstring tendons.

Figure III. Current autograft options for the ACL reconstruction. QTPB = quadriceps tendon-patellar bone autograft, BTB = bone-patellar tendon-bone autograft, STG = semitendinosus-gracilis-tendon autograft.



The BTB autograft procedure has shown the most predictable long-term results (Shelbourne et al. 1990, Shelbourne and Gray 1997), and in 1990s this reconstruction was considered the golden standard procedure (Fu and Schulte 1996, Järvinen et al. 1995, Renström 1991, Shelbourne and Gray 1997). The BTB autograft has been a popular graft for ACL replacement because of its high ultimate tensile load (approximately 2300 N), its stiffness (approximately 620 N/mm) (Schatzmann et al. 1998), and the possibility for rigid fixation with its attached bony ends providing good mechanical strength of the graft (Aglietti et al. 1994, Muneta et al. 1998, Shelbourne et al. 1995, Roos and Karlsson 1998). The BTB graft is often selected for young, high-demand athletes, because it allows the earliest return to strenuous activities (Fu et al. 2000). However, anterior knee pain, patellofemoral problems, and delayed recovery of the knee extension strength are associated with this procedure (Rosenberg et al. 1992, Aglietti et al. 1993, Natri et al. 1996, Shelbourne and Trumper 1997, Stapleton 1997, Kartus et al. 1999).

Recently, the semitendinosus and gracilis tendons (STG) have been used as an alternative reconstruction material, and good results have been reported in short-term follow-ups (Siegel and Barber-Westin 1998, Corry et al. 1999). The ultimate tensile load of the quadrupled STG graft has been reported to be as high as 4108 N (Brown et al. 1993). However, with this procedure, stability of the knee does not seem to be as good as with the BTB procedure (Aglietti et al. 1994, Muneta et al. 1998). Especially, with female patients the laxity of the knee seems to increase in the course of time (Corry et al. 1999). Fixation site healing of the hamstring tendons graft within the osseous tunnel is still under investigation, and for the present, the weakest link in the use of the hamstring tendon graft is the fixation of the graft, especially at the tibial side. The advantages of the hamstring tendon graft include a smaller incision and less anterior knee pain (Corry et al. 1999). At present, the most commonly used grafts for ACL reconstructions are autograft BTB and hamstring tendon grafts (Fu et al. 2000).

The advantages of the quadriceps tendon-patellar bone autograft for the ACL reconstruction include a potentially wide tendinous portion along with a rigid bone plug fixation at one end. Biomechanical studies have shown the ultimate tensile load of this graft to be as high as 2352 N (Schatzmann et al. 1998), and it is of sufficient size and strength to be used for ACL reconstruction (Harris et al. 1997). Disadvantages include the size and location of the donor-site scar (Fu et al. 2000). This procedure has been introduced as an alternative method for ACL reconstruction or for revision of failed BTB graft reconstruction when the central third patella tendon has already been used (Fulkerson and Langeland 1995, Chen et al. 1999).

Allograft tissues, such as the Achilles tendon and bone-patellar tendon-bone, have also been used for ACL reconstruction (Victor et al. 1997, Zijl et al. 2000). However, the graft material has to be carefully screened for viral disease, and also appropriate harvesting, sterilization, and preservation techniques that do not weaken the graft, have to be used (Fu et al. 2000). Clinical studies with 7-year follow-up demonstrate that the outcomes of ACL allograft reconstruction are similar to those of autograft reconstructions (Noyes and Barber-Westin 1996). However, Noyes and Barber-Westin (1996) still recommended reconstruction with a BTB autograft as the first choice for an acute rupture of the ACL.

The advantages and disadvantages of the current graft options are summarized in the Table I, and the ultimate tensile load of the intact human ACL and the most common ACL replacement grafts in the Table II.

Table I. Current graft options for ACL reconstruction.

Graft	advantages	disadvantages
Bone-patellar tendon-bone (BTB)	good stability good mechanical strength firm bony fixation fast return to high-demand sports suitable for aggressive rehabilitation extensive worldwide experience	anterior knee pain patellofemoral osteoarthritis? knee extension strength deficit
Semitendinosus/ gracilis (STG)	smaller incision less anterior knee pain less patellofemoral problems good knee extension strength widely used	relatively unstable rehabilitation have to be slower lack of rigid bony fixation healing within the tunnels?
Quadriceps tendon-patellar bone	sufficient size good strength alternative method for revisions	donor-site scar and pain lack of wide experience
Allografts (Achilles, BTB, hamstrings)	no donor site problems alternative method for revisions or simultaneous ACL and PCL reconstruction	risk for viral disease not so available not widely used

Table II. Ultimate tensile load of the intact human ACL and the most common ACL replacement grafts, Mean (SD).

Graft type	Ultimate tensile load, (N)	Reference
Intact ACL	2160 (157)	Woo et al. 1991
Bone-patellar tendon-bone (10 mm)	2376 (151)	Schatzmann et al. 1998
Quadruple hamstring graft	4108 (200)	Brown et al. 1993
Quadriceps tendon (10 mm)	2352 (495)	Schatzmann et al. 1998

SD= standard deviation
N= Newtons

4.7. Graft placement

The reconstruction of the ACL is a demanding operation. The graft must be placed to an optimal position in the knee, which mimics the position of the original ACL (Hefzy et al. 1989, Lintner et al. 1996). This isometric position allows good stability of the knee joint during the whole range of motion. Also, the length of the graft has to be suitable to make sure that the original length of the ACL is remained (Högerle et al. 1998). However, recently the demands for optimal graft placement in ACL reconstructions have been revised with advances in understanding the importance of each bundle of the ACL (Fu et al. 1999).

Previously, the femoral attachment of the graft was considered extremely important to receive the isometric position of the graft (Draganich et al. 1996, Manaster et al. 1988, Recht et al. 1996). However, some recent studies have shown that placing the graft on the average most isometric femoral line did not restore knee stability to normal in all knees (Draganich et al. 1999). This finding supports the need to customize graft placement in each knee at the time of surgery. In cases undergoing revision surgery of the ACL, Sommer et al. (2000) found that among 63 patients the most common error in the primary ACL reconstruction was that the femoral attachment was too anterior to the anatomical insertion of the ACL.

A nonoptimal tibial attachment of the graft seems to play a role in development of graft impingement (Howell and Clark 1992, Yaru et al. 1992), and graft failure (Almekinders et al. 1998). Also, in the tibial site, too anteriorly placed tibial tunnel tends to result worse clinical scores (Zijl et al. 2000). A number of investigators advocate to place the graft to at the posterior portion of the tibial insertion site of the ACL (near the posterolateral bundle position), to best reproduce the normal function of the ACL (Amis and Jakob 1998, Howell and Barad 1995).

4.8. Graft fixation

Fixation of the graft should ideally restore the original anatomy of the ACL. Therefore, fixation should be as close to the joint line as possible (Fu et al. 2000). With interference screws this kind of fixation is possible. Several studies have shown that fixation strength of metallic interference screws and bioabsorbable interference screws are equal for the BTB autograft (Kousa et al. 1995, Seil et al. 1998, Hoffmann et al. 1999, McGuire et al. 1999), and for the STG autograft (Barber 1999). The length of the screw, however, seems to have no influence for the fixation strength of the graft (Stadelmeier et al. 1999).

Hamstring tendon graft fixation can also be achieved with techniques that secure the graft near the tibial and femoral cortices. The femoral-sided endobutton and tibial-sided screw and washer have been used to achieve good hamstring tendon graft fixation (Rowden et al. 1997). However, bone tunnel enlargement has been reported after using this technique for ACL reconstruction, but the importance of this occurring is not clear, because clinically these patients did well two years after the ACL reconstruction (Jansson et al. 1999). Tunnel enlargement has been also reported, when using bioabsorbable interference screws for the hamstring tendon graft fixation (Buelow et al. 2000), although the incidence of the tunnel enlargement with this technique seems to be lower when compared the studies using an extracortical fixation for hamstrings (Insalata et al. 1997, Jansson et al. 1999).

Magen et al. (1999) compared six tibial fixation methods using freshfrozen animal tissue and human donors (gracilis and semitendinosus tendons and tibias). Biomechanically, tandem washer was the best fixation method. Interference screw fixation performed well in animal tissue, but was significantly worse in young human tissue, with 57 % of the fixations failing before 500 N of load. Because of this, they concluded that the ability to provide adequate fixation with interference screws, and after the use of STG graft, intensive rehabilitation should be questioned.

Usually, the interference screw fixation of the STG graft is placed in the femoral and tibial tunnels eccentric (adjacent) to the bundled limbs of the graft. In order to maximize the graft-to-tunnel contact to promote biological fixation, it is proposed to place the screw concentrically in the tunnel, in the middle of the four limbs of the graft, pressing each limb of the graft into the tunnel wall. This would be difficult to do in the femoral tunnel but can be done easily in the tibial tunnel. Shino and Pflaster (2000) have found in their study of five pairs of fresh frozen human cadaver knees that the tibial fixation stiffness was greater using concentric screw placement when comparing eccentric screw placement. However, Simonian et al. (1998) did not find any statistical differencies in the maximum pullout forces between the concentric and eccentric screw fixation in their study of six fresh human cadaveric knee specimens.

A new bioabsorbable plug fixation technique in the femoral site has been introduced when using the BTB autograft (Kousa et al. 2001), and in fact, this kind of fixation was equal with a conventional interference screw fixation in the porcine model. Also, a press-fit technique has been described for the ACL reconstruction (Boszotta 1997), but it did not provide a secure fixation in all cases (Seil et al. 1998). Five press-fit specimens from 30 cases in a porcine model failed under cyclic loads comparable with those seen under conditions of accelerated rehabilitation (Seil et al. 1998).

Besides the fixation method used, several studies have also shown the importance of the initial graft tension in the fixation of the graft for ACL reconstruction (Yasuda et al. 1997, Hamner et al. 1999). A low initial graft tension will not provide joint stability, while on the other hand, an exceedingly high initial graft tension can restrain joint motion and compromise graft survivability (Fu et al.1999). All strands of a hamstring graft must be under equal tension for the composite to have its optimum biomechanical properties (Hamner et al. 1999). Also, the graft preconditioning (pretensioning) and reproduction of normal graft rotation have been under the investigation. However, the clinical importance of graft rotation is still unclear (Samuelsson et al. 1996), while the preconditioning of the graft seems to have some role in ACL reconstruction with a STG graft (Fu et al. 2000).

Significant amount research has been performed on the ultimate tensile load of various fixation devices of the ACL. However, these studies have been performed with cadaveric knees from elderly donors or with animal models so that the result may not represent the ultimate tensile load of the device when used clinically. The ultimate tensile load of various fixation devices using human cadaveric knees are presented in the Table III. However, cyclic loading test is advocated at present as a better means to predict how a device will do clinically (Beynnon and Amis 1998).

Table III. Ultimate tensile load of various fixation devices using human cadaveric knees, Mean (SD).

Type of fixation device	Ultimate tensile load (N)	Reference
Direct soft tissue		
Metal interference screw (7 mm)	242 (90)	Caborn et al. 1998
Bioabsorbable screw (7 mm)	341 (163)	Caborn et al. 1998
Bone mulch screw	1126 (80)	Magen et al. 1999
Tandem soft tissue washers	768	Magen et al. 1999
Direct bone		
Metal interference screw (7 mm)	640 (201)	Pena et al. 1996
Metal interference screw (9 mm)	276-436	Johnson et al. 1996 Matthews et al. 1998
Bioabsorbable screw (7 mm)	330-418	Pena et al. 1996
Bioabsorbable screw (9 mm)	565	Johnson et al. 1996
Stables	588	Gerich et al. 1997

SD= standard deviation, N= Newtons

4.9. Timing of the surgery

Some studies have shown that the optimal time for the ACL reconstruction is probably not earlier than four to six weeks after the ACL injury, because the risk for arthrofibrosis may increase if the reconstruction is done too soon after the injury (Shelbourne et al. 1991), while some studies have reported no difficulties in obtaining a full range of motion of the knee after early ACL repair (Majors and Woodfin 1996, Noyes and Barber-Westin 1997). Shelbourne and Foulk (1995) showed that quadriceps muscle strength returns quicker after delayed (mean, 40 days after injury) ACL reconstruction with a BTB graft when comparing early (mean, 11 days after injury) similar ACL reconstruction.

In a five-year follow-up study of Marcacci et al. (1995), the patients who had an ACL reconstruction during the early phase (within 15 days of injury) returned to sports activities sooner and had better clinical and laxity testing results than the patients with late reconstruction (more than 3 months after injury). They concluded that early surgery in young, motivated athletes can be performed without a greater risk of loss of motion than in patients with late reconstruction, if the procedure is followed by an accelerated rehabilitation program. Furthermore, these authors noted that early reconstruction of the ACL may prevent the onset of proceeding instability or secondary degenerative lesions. Noyes and Barber-Westin (1997) also recommended early ACL reconstruction (less than 3 months after the injury) for active persons in their two-year follow-up study of 87 patients.

4.10. Postoperative rehabilitation

Restoration of musculoskeletal function is a fundamental goal of all orthopedic treatment (Dye et al. 1998). In the ACL surgery, these goals also include full range of motion and good stability of the index knee. However, if compromises have to be made, it is better to have a knee with a full range of motion with somewhat compromised laxity than a stiff knee with excellent stability.

Järvinen and Kannus (1997) have found that injury of the lower extremity is a clear risk factor for the development of osteoporosis in the same extremity. In their study, the 31 patients who had sustained a severe injury of the knee (a complete rupture of the ACL alone or in combination with ruptures of other ligaments) and had been managed operatively with primary repair of the ligament and postoperative immobilization in a plaster cast for six to seven weeks, had remarkable average bone loss in the distal aspect of the femur, patella, and proximal aspect of the tibia of the injured limb. They recommended that the treatment of injuries of the lower extremity should involve short periods of immobilization only, early weightbearing, and a well planned program of rehabilitation.

Current trends in rehabilitation after ACL reconstruction suggest aggressive or accelerated exercise protocols that allow immediate full weightbearing without brace, and return to high levels of athletic activity (running, cutting, twisting, turning) as early as three to four months after surgery (Shelbourne et al. 1995, Shelbourne and Gray 1997). These studies have shown that patients treated with a BTB autograft and subsequent aggressive and accelerated rehabilitation program have obtained long-term stability and full range of motion of the knee with a low complication rate, and have been able to return to full sporting activities predictably.

Also, less aggressive rehabilitation programs have been introduced. The rehabilitation program of the study of Barber-Westin et al. (1999) consisted of immediate knee motion and early weightbearing, but return to fully competitive sports activities was delayed for at least eight months. They concluded that their rehabilitation program was not injurious for the graft, because the failure rate a minimum two years after the surgery was acceptable (5%). However, Muneta et al. (1998) found that in 103 patients aggressive early rehabilitation after the ACL reconstruction with the semitendinosus (and gracilis) tendon had a higher risk for residual laxity than similar rehabilitation after reconstruction with the BTB graft. They concluded that the method of fixation for the tendon graft in the STG procedure needs improvement.

Recently, a prospective, randomized 2-year follow-up study on the effect of knee bracing after ACL reconstruction was reported (Risberg et al. 1999). In this study, the patients in the braced group wore rehabilitative braces for two weeks, followed by functional braces for ten weeks, while the patients in the nonbraced group did not wear braces at all. During the follow-up, there were no significant differences between the two groups with regard to knee joint laxity, range of motion, muscle strength, functional knee tests, or pain. However, prolonged bracing (one to two years after surgery) produced a significant decrease in quadriceps muscle strength compared with bracing for a shorter period.

4.11. Postoperative problems

ACL reconstruction is not without postoperative problems. One of them is patellofemoral osteoarthritis, which often occurs with pain, crepitation, and incomplete range of motion of the knee (Aglietti et al. 1993, Aglietti et al. 1994). Also, several reports have shown that the patellar tendon shortens after an ACL reconstruction with a BTB autograft, if the defect of the residual tendon is closed (Breitfuss et al. 1996, Muellner et al. 1998, O`Brien et al. 1991, Paulos et al. 1994). However, the significance of this occurring with respect to the subjective and clinical outcome of the surgery has remained unclear. Because direct closure of the patellar tendon after harvesting may lead to shortening of the patellar tendon, suturing of the patellar tendon paratenon only has been proposed (Fu et al. 2000). However, Brandsson et al. (1998) found no between-groups differences when comparing two randomly allocated groups of patients with BTB autograft. In the first group, the defect of the patellar tendon was closed and the patellar defect was filled with bone graft, while in the other group, both the tendon gap and patellar defect were left open.

Anterior knee pain, and delayed and often incomplete recovery of the knee extension strength are also associated with ACL reconstructions, especially when using a BTB autograft (Rosenberg et al. 1992, Natri et al. 1996, Shelbourne and Trumper 1997, Stapleton 1997, Kartus et al. 1999). To prevent the postoperative anterior knee pain Shelbourne and Trumper (1997) recommended aggressive rehabilitation immediately after surgery. Kartus et al. (1999) have shown in their studies of dissection and magnetic resonance imaging (MRI) that one of the main reasons for the anterior knee pain is the damage of the infrapatellar nerves in the graft-harvesting. They concluded that the subcutaneous graft-harvesting technique produced significantly less disturbance in anterior knee sensitivity and a significantly smaller residual donor-site gap, compared with the traditional technique.

In addition to the above noted problems, ACL surgery may include some rarer complications, too. These complications include arthrofibrosis (Shelbourne et al. 1991), deep venous thromboses, wound infections, reflex sympathetic dystrophy, intraarticular placement of bone blugs, distal femoral shaft fracture (Wiener and Siliski 1996), patellar fracture (McCarroll 1983, Viola and Vianello 1999), patellar tendon rupture (Bonamo et al. 1984), intraarticular migration of a femoral interference screw (Sidhu and Wroble 1997), and herniation of the patellar fat pad through the patellar tendon defect (Johnson et al. 1996).

4.12. Accompanying injuries

ACL ruptures are often combined with meniscal tears (Arangio and Cohen 1998), and together they can lead to degenerative changes of the knee (Maletius and Messner 1999). Some studies have reported good results after meniscal repair (Asahina et al. 1998, Barber and Click 1997, Barrett et al. 1997). However, not all meniscal tears are repairable, and partial meniscectomy has been considered acceptable for complex meniscal tears (Schmitz et al. 1996), although many studies have shown that in a long run even partial meniscectomy can lead to degenerative changes of the knee (Aagaard and Verdonk 1999, Burks et al. 1997, Jomha et al. 1999, Lewandrowski et al. 1997, Maletius and Messner 1996, Rangger et al. 1995, Schimmer et al. 1998).

A MCL rupture is also often combined with an ACL rupture, unlike PCL- and LCL-ruptures (Arangio and Cohen 1998). Combined ACL-MCL injuries can lead to more serious degenerative changes of the knee than an isolated rupture of the ACL or MCL (Kannus 1988, Lundberg and Messner 1997). Some studies have recommended conservative treatment of the MCL when the ACL is repaired after a combined ligamentous injury (Hillard-Sembell et al. 1996, Petersen and Laprell 1999), while other authors have preferred surgical management of the MCL in combined injuries (Fröhlke et al. 1998).

Goal in the treatment of ACL-PCL-LCL injuries is to restore functional and objective stability to the injured knee. It is also important to make sure that the neurovascular status of the injured limb is in a good shape. These knees are at high risk for progressive instability, and the development of posttraumatic osteoarthritis. Therefore, the surgery should be performed as close to the time of injury as is safely possible. Special considerations that affect the timing of surgery include vascular status of the extremity, stability of the knee after reduction of the dislocated knee, skin condition, multiple system injuries, open injuries, and other injuries (Fanelli 2000).

There seems to be a tendency that the MCL and the PCL do heal after injury, while the ACL and the LCL do not heal well without surgery. Therefore, knee dislocations with lateral side complex injuries require immediate attention. If surgical repair is performed within 3 weeks after injury, lateral stability can be established reliably by repairing the injured structures (Shelbourne and Klootwyk 2000). Latimer et al. (1998) have described a new promising technique for reconstruction of the lateral collateral ligament of the knee with patellar tendon allograft for patients with late instability resulting from lateral ligament injuries of the knee. However, there were only ten patients in their study thus preventing extended conclusions.

5. AIMS OF THE STUDY

1. to evaluate the results of the BTB reconstruction (using miniarthrotomy technique) five to nine years after the procedure.

2. to compare the results when the reconstruction was done within six weeks versus over three months after the injury.

3. to evaluate the predicting factors of anterior knee pain five to nine years after an ACL reconstruction with BTB autograft

4. to evaluate the degree of patellofemoral osteoarthritis after an ACL reconstruction with BTB autograft and to analyze the relationship of patellofemoral osteoarthritis to the postoperative shortening of the patellar tendon.

5. to develop a new method to evaluate simultaneously the femoral and tibial tunnel placements of the graft from a lateral knee radiograph and to analyze the relationship between the graft position and clinical outcome of the patients.

6. to compare the clinical and radiological results in patients with an isolated rupture of the ACL to those with an ACL rupture and accompanying injuries five- to nine-year after the BTB procedure.

6. PATIENTS AND METHODS

6.1. Patients

The 144 patients who underwent an ACL reconstruction (using the BTB autograft and miniarthrotomy technique) in the Tampere University Hospital between January 1989 and December 1991 formed the basic population of this study series. Of these 144 patients, 130 (90%) patients could be contacted and interviewed with a questionnaire and 101 (70%) patients were able to attend the follow-up examination. Gender, age at the time of operation, weight, height, delay between the injury and reconstruction, and follow-up time of the 101 patients are presented in the Table IV. Eighty-three (64 %) of the 130 interviewed patients had sustained the ACL tear in sports, 16 (12 %) in traffic, 13 (10 %) during work, 12 (9 %) during free time activities, and six (5 %) at home.

Table IV. Gender, age at the time of operation, weight, height, the delay between the injury and the reconstruction, and the follow-up time of the 101 patients.

Gender	male n=70	female n=31
Age at the time of operation (years)	30.5 (16-51)*	30.5 (15-61)*
Weight (kg)	83.8 (60-109)*	65.7 (50-95)*
Height (cm)	178.7 (165-194)*	165.3 (154-175)*
Delay (years)	2.0 (0-20.1)*	1.0 (0-9.8)*
Follow-up time (years)	7.0 (5.4-8.8)*	6.8 (4.6-8.4)*

*Mean (range)

6.1.1. Studies I and II

Among the 101 reexamined patients, there were 70 men and 31 women. In the study I, the patients were divided into two groups: In the Group I (early reconstruction group), the ACL reconstruction had been done within six weeks of the injury (n=53) while in the Group II (late reconstruction group) the reconstruction was done later than three months after the injury (n=48). In ten patients (five in the Group I and five in the Group II), a reconstruction of the ACL of the contralateral knee was performed during the follow-up, and these patients were excluded from the statistical analysis when comparing the injured knee with the uninjured knee at the follow-up examination, thus leaving 48 patients to the Group I and 43 patients to the Group II. Also, in the study II, these ten patients with an ACL reconstruction of the contralateral knee were excluded from the final analysis.

In the study I, the Group I included 29 men and 19 women, with a mean age of 32 years (range 15-61 years) at the time of the surgery. The mean delay between the injury and the reconstruction was six days (range, 0-43 days), and the mean follow-up time 7.0 years (range, 5.9-8.5 years). The Group II included 34 men and 9 women, with a mean age of 30 years (range 16-46 years) at the time of the operation. The mean delay between the injury and the reconstruction was three years and seven months (range, 3 months-20 years), and the mean follow-up time 7.0 years (range, 4.6-8.8 years). There were no statistically significant differences between the groups for the variables of sex, age, height and weight, or the length of the follow-up.

Of the 101 patients, 27 patients had had previous surgical procedures. In the study I, three procedures had to be done in the Group I, while this was the case in 24 patients in the Group II ($p<0.005$) (Study I: Table 2).

Postoperatively, there were four wound infections (one in the Group I and three in the Group II, in the study I), and two venous thromboses (both of them in the Group I). In the Group I, two manipulations under anesthesia and seven arthroscopic divisions of adhesions had to be done later on, while in the Group II five arthroscopic divisions of adhesions were done because of the persisting flexion-extension deficit in the operated knee. Four patients sustained a new injury to the reconstructed knee (two in the Group I and two in the Group II), but only one re-reconstruction of the ACL was needed (that was in the Group I).

6.1.2. Studies III and IV

In these studies, the major concerns were the radiological changes of the injured knees when comparing the situation before the ACL reconstruction and after follow-up. Therefore, the ten patients with the ACL reconstruction of the contralateral knee were not excluded from these studies. However, one patient was pregnant, and she was not able to take part of the radiological examinations. So, the final number of the patients in studies III and IV was 100.

Among the 100 patients, there were 70 men and 30 women with a mean age of 31 (range 15-61 years) at the time of surgery. The mean delay between the injury and the reconstruction was 1.7 years (range: 0 days to 20 years). Forty-five patients were operated within one week, six between one and two weeks, three between two and eight weeks, seven between two and six months, nine between six and twelve months, and 30 more than one year after the injury. The mean follow-up time was 7.0 years (range 4.6-8.8 years).

6.1.3. Study V

In the study V, the 102 patients (of the initial 144 patients) who did not have previous knee surgery or surgery of the contralateral knee during the follow-up, formed the basic population of the study. Of these 102 patients, 93 (91%) patients could be contacted and interviewed with a questionnaire and 72 (71%) patients were able to attend the follow-up examination. There were 34 patients (25 men, 9 women) in the group with an isolated ACL tear (group A), and 38 patients (23 men, 15 women) in the group with an ACL tear with accompanying injuries (group B). In the group B, there were 10 medial and 12 lateral meniscal tears, 19 MCL ruptures , two LCL ruptures, and one PCL rupture (Table V).

Table V. ACL tear with or without accompanying injuries.

Injury	n
Isolated ACL tear	34
Accompanying injuries	38
ACL + MCL	16
ACL + MCL + med. meniscus	1
ACL + MCL + lat. meniscus	1
ACL + MCL + PCL	1
ACL + LCL	2
ACL + med. meniscus	6
ACL + lat. meniscus	8
ACL + med. et lat. meniscus	3

6.2. Surgical technique of the ACL reconstruction

In all patients, miniarthrotomy technique with a BTB autograft was used. A 10 cm longitudinal skin incision was made in the midline of patellar tendon. The superficial fascia was reflected and the medial and lateral edges of the tendon defined. The central third of the tendon, about 9 mm in width, was removed with bone plugs at both ends. A miniarthrotomy was then carried out, the underlying fat and synovium being incised in sagittal direction and the intercondylar area exposed. A notchplasty was performed so that the osteochondral junction at the posterior inlet of the femoral notch could be felt by the finger.

A drill guide was used for a precise placement of the femoral and tibial drill holes, since one of the most important parts of the operation was to ensure the accurate anatomical location of the drill holes. The patellar tendon graft was fitted (with the bone plugs at its both ends) into drilled holes and fixed with 6.5 mm AO cancellous screws, the screws inserted between the plug and the bony tunnel. The femoral site was fixed first and before screwing the tibial site the isometric position of the graft was tested by flexing and extending the knee. Finally, the patellar tendon defect was closed with sutures.

6.3. Postoperative rehabilitation

After the surgery, the knee was fixed with a brace in 35 degrees of flexion for the first two weeks, and nonweightbearing walking was allowed with crutches. After two weeks, the hinges of the brace were adjusted to allow movement from 30 degrees to 60 degrees and weightbearing was gradually increased. Isometric quadriceps muscle exercises were started on the first postoperative day, followed later on by isotonic quadriceps training. The brace was removed five to seven weeks after the surgery, and full weightbearing was allowed. Running was allowed 12 to 16 weeks after the surgery, while ball games were not permitted until after six months.

6.4. Follow-up evaluation

The clinical follow-up evaluation was done by one surgeon (TJ). He had operated none of the patients. The evaluation was performed using the standard knee ligament evaluation form of the International Knee Documentation Committee (IKDC) (AOSSM, ESSKA) (Hefti et al. 1990) and the Lysholm and Gillquist (1982) (0 to 100 points) and the Marshall et al. (1977) (0 to 50 points) knee scores. The parameters of the IKDC included 1) subjective assessment of the knee, 2) knee symptoms (pain, swelling, and partial or full giving way), 3) range of motion (knee flexion and extension measured with a goniometer), 4) stability evaluation (Lachman, anterior drawer, medial and lateral joint opening, and pivot shift tests), 5) evaluation of patellofemoral and tibiofemoral crepitation, 6) anterior knee pain, 7) radiographic evaluations (weightbearing anteroposterior, lateral and patellofemoral projections) and 8) the single-legged hop test for distance (the test was performed three times, averaged, and compared with the opposite limb). According to the IKDC, all the parameters were graded as A) normal, B) nearly normal, C) abnormal or D) severely abnormal, and the first four parameters were included in the final evaluation of the IKDC rating system when comparing the injured to the uninjured knee. In the IKDC system, the lowest gradation within a group determines the group gradation, and the worst group gradation determines the final evaluation.

6.5. Symptom evaluation

In the symptom evaluation, the absence of pain, swelling and giving way were assessed as ”normal”. ”Nearly normal” indicated that patients were able for moderate activity without these symptoms, ”abnormal” that light activity was possible, and ”severely abnormal” that no activity was possible without symptoms, respectively.

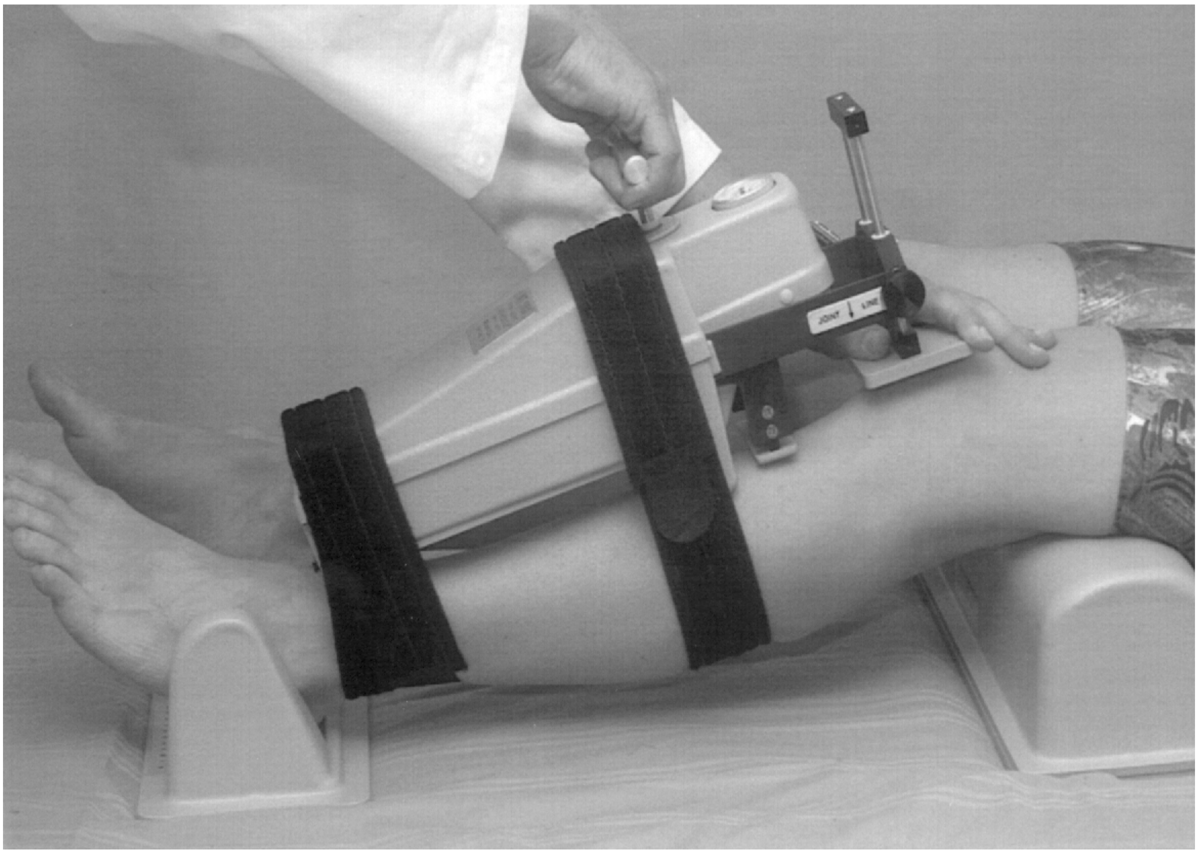
6.6. Range of motion of the knee

The measurements of the range of motion of the knee were performed with a goniometer, and the interlimb difference was recorded to the final evaluation of the IKDC. If the lack of knee extension was less than three degrees and the lack of knee flexion less than five degrees (as compared to the other side), the range of motion was considered ”normal”. If the lack of extension was three to five degrees or the lack of flexion six to fifteen degrees, the range of motion was considered ”nearly normal”. If then the lack of extension was six to ten degrees or the lack of flexion 16 to 25 degrees, the range of motion considered ”abnormal”, and greater than these flexion-extension deficits were considered ”severely abnormal”.

6.7. Knee laxity measurements

The knee laxity measurements (anteroposterior stability) were made with the KT-1000 arthrometer (MEDMetric, San Diego, California), as described by Daniel et al. (1985) at 30 degrees of flexion of the knee using a force of 89 Newtons (Figure IV). The laxity was measured twice in the injured and uninjured knees and an average value was recorded. The anterior displacement was registered as the difference between the injured and the non-injured knee (side-to-side laxity). The result of the test was graded as normal (0 to 2 mm laxity), nearly normal (3 to 5 mm laxity), abnormal (6 to 10 mm laxity) and severely abnormal (> 10 mm laxity).

Figure IV. The knee laxity measurement with the KT-1000 arthrometer.



6.8. Isokinetic strength testing

The isokinetic extension and flexion strength evaluation of the knees (Cybex 6000, Lumex, Inc., Ronkonkoma, New York) was performed with the knee angle velocities of 60 (5 repetitions), 180 (5 repetitions) and 240 (25 repetitions) degrees per second and the interlimb difference was recorded. The recovery time between tests of different knee angle velocities was 30 second. Before testing, patients had five minutes of warm-up section with a cycle ergometer. The non-operated limb was examined first. Identical instructions were given to the patient during each test. One patient was unable to complete the test because of pain. Circumferences of the thighs were measured 15 cm above the joint line and the difference between thighs was recorded.

6.9. Radiographic analysis

The radiographic analysis of the knees was done by one experienced radiologist (TP) and the follow-up x-rays of the injured knee were compared to those of the uninjured knee as well as to those of the injured knee taken before the ACL reconstruction. Literature provides several scoring scales for radiological evaluation of post-traumatic osteoarthritis of the knee joint (Iwano et al. 1990, Kannus et al. 1988, Sherman et al. 1988); for this study the IKDC evaluation system was selected (Hefti et al. 1990). A bilateral antero-posterior weightbearing roentgenogram at 35-45 degrees of flexion (tunnel view) was used to evaluate narrowing of the medial and lateral joint spaces. The Merchant (Merchant et al. 1974) view at 45 degrees was used to document medial and lateral patellofemoral narrowing. A mild grade indicated minimal changes (e.g., small osteophytes, slight sclerosis or flattening of the femoral condyle), but the joint space was wider than 4 mm. A moderate grade might have those changes and joint space narrowing (e.g., a joint space of 2-4 mm wide). Severe changes included significant joint space narrowing (e.g., a joint space less than 2 mm).

6.10. Measurements of the graft placement from the lateral radiograph

Measurements was done by one experienced radiologist together with the surgeon, who had not operated any of the patients. Tunnel width was measured and the tunnel center, at the level of entry into the joint, was marked as a point to describe the graft location. Two different techniques were used for measuring the placement of the femoral tunnel.

In the first technique, a straight and tangential line was drawn along the posterior surface of the diaphysis of the femur extending to the knee joint across the intercondylar roof or Blumensaat`s line. The reference point was at the junction of the Blumensaat`s line and the tangential line (called ”junction reference point”). The femoral tunnel placement of the graft was then measured along the Blumensaat`s line as a distance from this reference point (mm), and marked with a plus when the tunnel position was to posterior from the reference point, and with a minus when the tunnel position was to anterior from the reference point (Figure V).

In the second technique, the femoral tunnel placement was measured from the posterior surface of the femur condyle along the Blumensaat`s line, and compared it to the entire length of the femur condyle in the lateral radiograph. The tunnel position was expressed as a percentage from posterior-to-anterior (Figure VI).

For measuring the tibial tunnel placement, the distance from the anterior corner of the tibial plateau to the center of the tibial tunnel was measured and compared to the entire length of the tibial plateau in the lateral radiograph. The tibial tunnel position was expressed as a percentage of the anterior-to-posterior length of the tibial plateau (Figure VII).

In order to evaluate both femur and tibial tunnel placements simultaneously, we summed up the percentages of femoral and tibial tunnel placements, and received a sum, which we called ”the sum score of the graft placement ”. The smaller the sum score the more horizontal or biomechanically more optimal was the graft position, and vice versa (the bigger the sum score the more vertical or less optimal was the graft position) (Figure VIII A, B).

Figure V. The method of "junction reference point" for measuring the placement of the femoral tunnel. The posterior tunnel placement from the junction of the two lines (along the Blumensaat`s line) was marked with a plus (mm), and to anterior with a minus (mm).

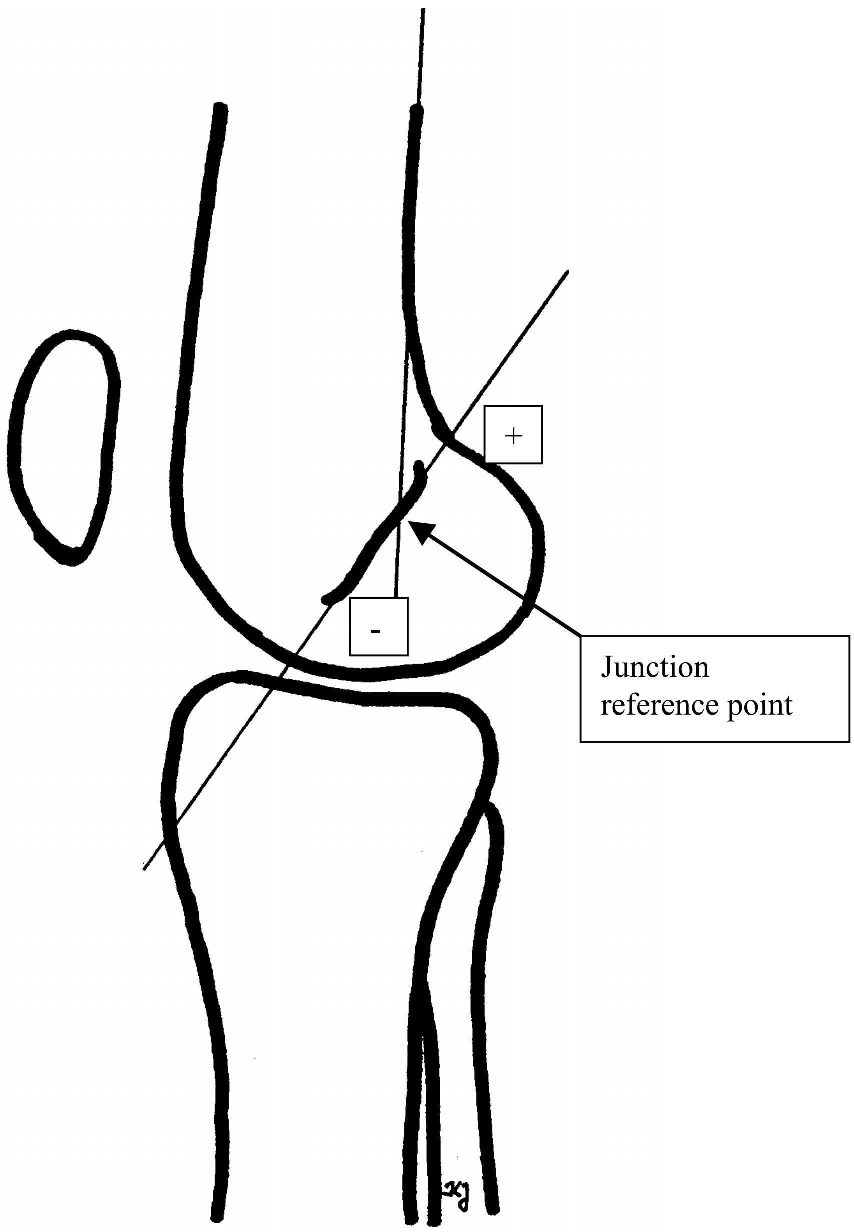


Figure VI. Femoral tunnel placement is measured from the posterior surface of the femoral condyle along the Blumensaat`s line to the center of the tunnel and reported as a percentage of the entire length of the femoral condyle.

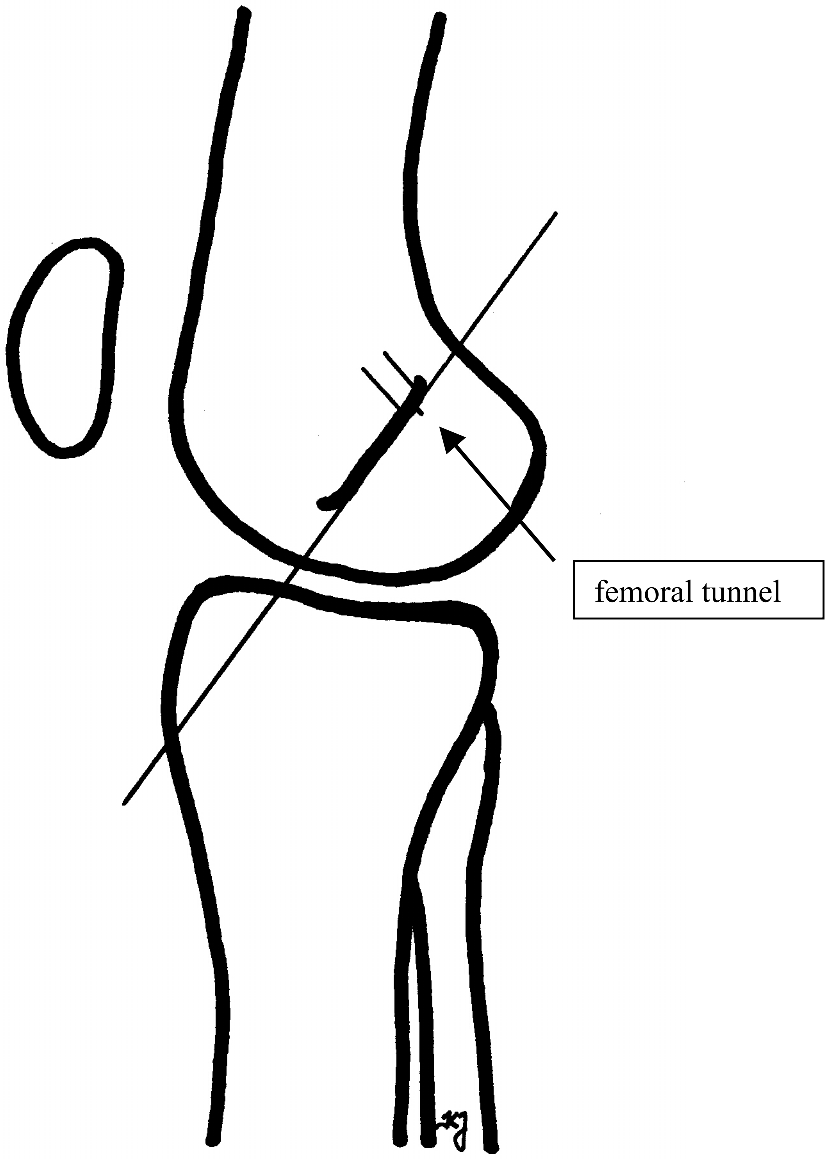


Figure VII. Tibial tunnel placement is measured from the anterior corner of the tibial plateau to the center of the tunnel and reported as a percentage of the entire length of the tibial plateau.

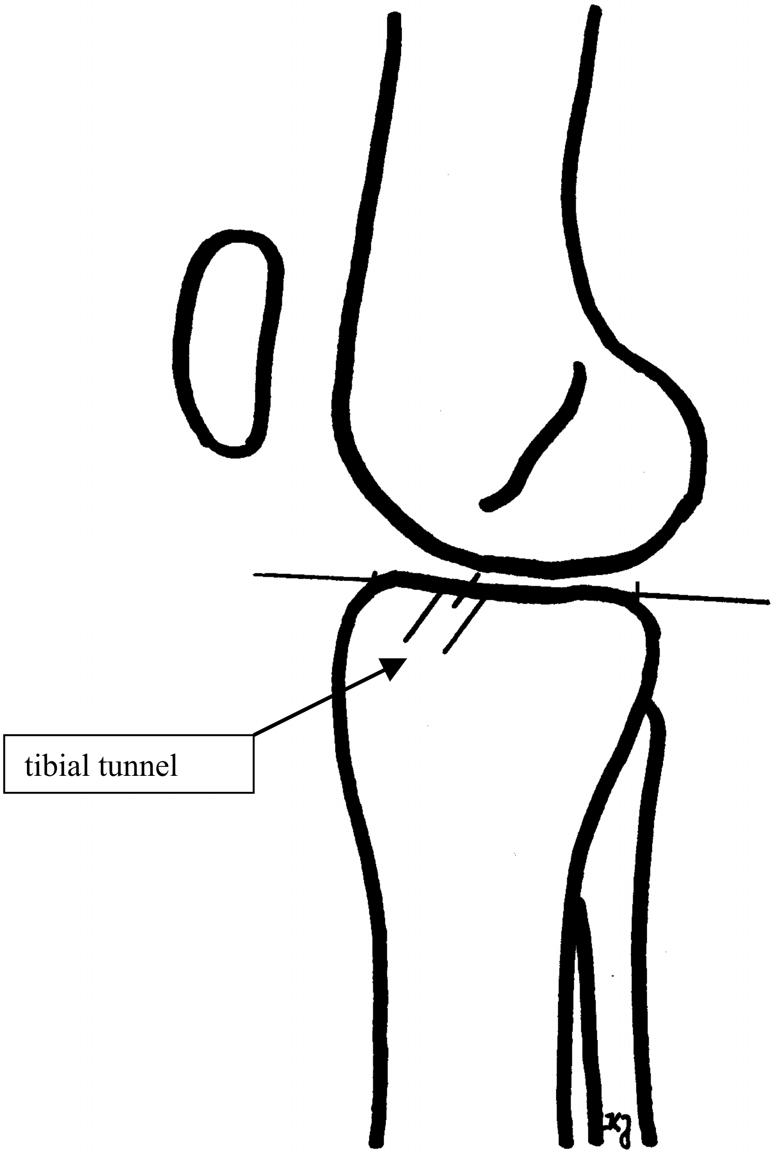
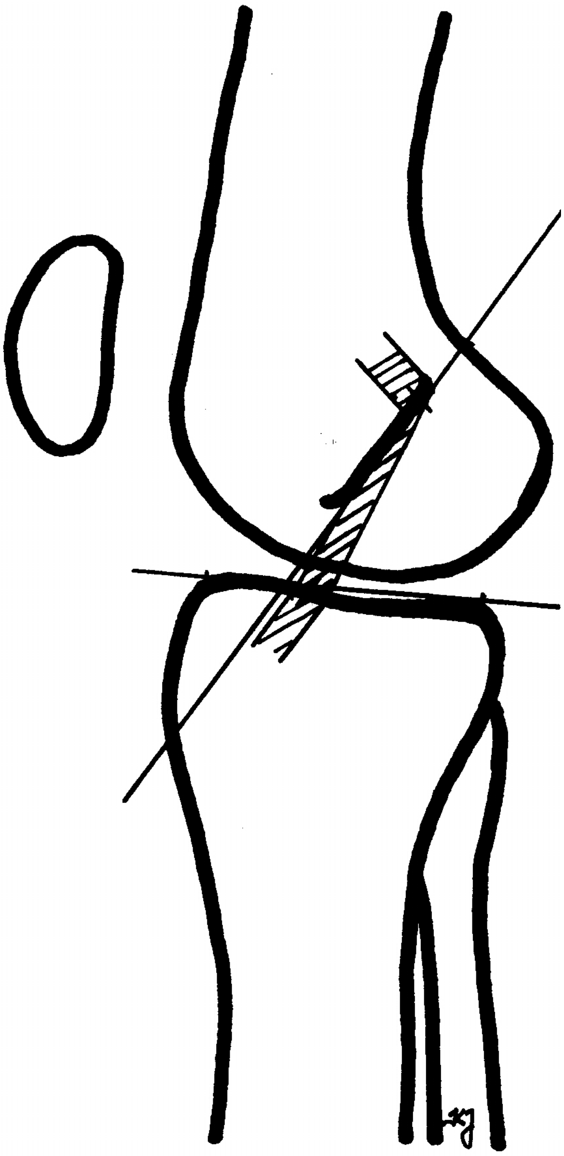
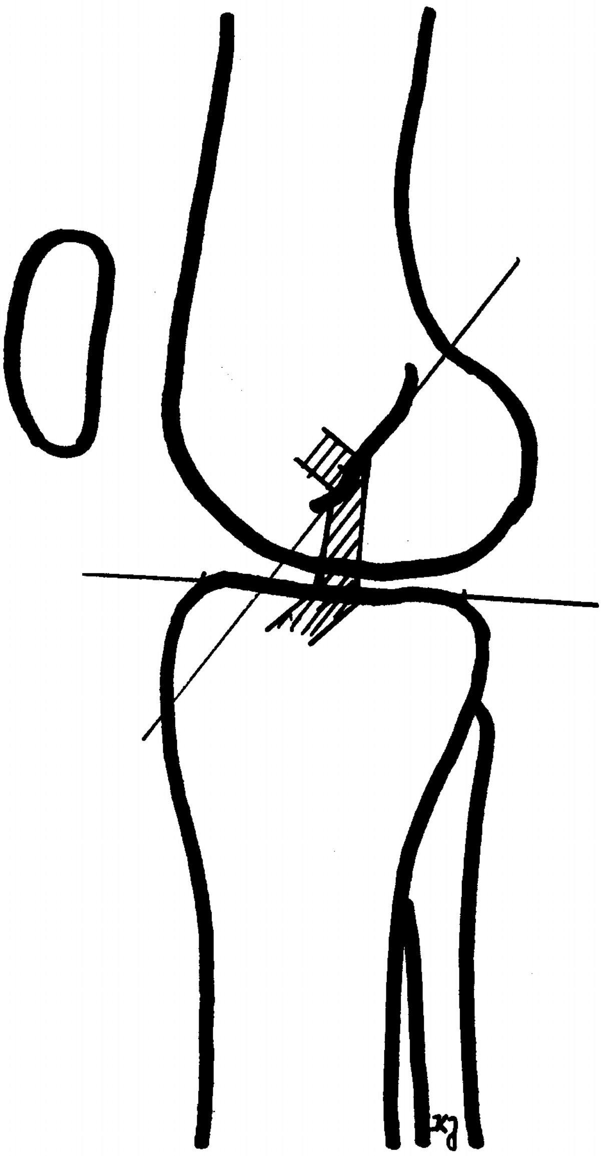


Figure VIII. ”The sum score of the graft placement” was received by summing up the percentages of femoral and tibial tunnel placements.



A) In this picture, ”the sum score of the graft placement” is 60 representing a biomechanically optimal graft placement.



B) In this picture, ”the sum score of the graft placement” is 110 representing less optimal graft placement.

6.11. Statistics

Statistical analysis was done using the SPSS 7.5 software package (SPSS, Inc., Chicago, Illinois). The calculations between the differences of means were done by analysis of variance (ANOVA), paired samples student t-test and those of the frequencies by the chi-square test. The significance level was chosen to be $p < 0.05$.

A logistic stepwise regression (forward-stepping) was performed in the study II. The 0.05 level of significance was used as a criterion to include a parameter in the model. In analysis of relationships, Pearson product correlation coefficients (r values) were also used (study IV). The significance level was set at $p < 0.05$.

7. **RESULTS**

7.1. Study I

7.1.1. Subjective final outcome after follow-up

In the Group I, 25 patients (52%) considered their knees normal, 20 (42%) nearly normal, and three (6%) abnormal at the time of the follow-up. In the Group II, 12 patients (28%) felt their knees were normal, 24 (56%) nearly normal, and seven (16%) abnormal. The group difference, in favor of the Group I, was significant ($p<0.05$).

In the symptom evaluation of the knee, 31 patients (65%) rated their knees as normal, 13 (27%) as nearly normal and four (8%) as abnormal in the Group I. In the Group II, the figures were 17 (40%), 20 (46%) and six (14%), respectively. Although the patients in the Group I had less knee symptoms than the patients in the Group II, difference between the groups was not statistically significant.

7.1.2. Objective final outcome after follow-up

In the Group I, the range of motion of the knee was normal in 26 (54%) patients, nearly normal in 16 (33%) patients, and abnormal in six (13%) patients. In the Group II, the corresponding numbers were 29 (67%), 12 (28%) and two (5%), respectively. The group difference was significant (in favor of the Group II) ($p<0.05$).

The results of the arthrometric antero-posterior laxity measurements did not show significant difference between the early and late reconstruction groups (Study I: Table 4). The injured-to-uninjured knee difference averaged 0.5 mm in the Group I and 0.3 mm in the Group II.

In the IKDC stability rating, 38 patients (79%) in the Group I had normal stability of the knee, 10 (21%) patients had nearly normal stability of the knee, and none of these patients had an unstable knee. In the Group II, 30 patients (70%) had normal stability of the knee, 11 (25%) patients had nearly normal stability of the knee, and two (5%) patients had an unstable knee (NS).

The presence of crepitation, anterior knee pain, degenerative changes in the knee, and the results of the ”single leg hop” test are summarized in Study I in Table 5. Patellofemoral crepitation was significantly more common in the Group II than in the Group I ($p<0.05$), whereas there was no significant difference between the two groups with the presence of tibiofemoral crepitation. Anterior knee pain was similar in both groups. The only significant degenerative change in the knee between the two groups appeared in the medial tibiofemoral joint, so that patients in the Group I had less degenerative changes than patients in the Group II ($p<0.05$). No significant difference between the two groups was found on the ”single leg hop” test, although 14 patients (4 in the Group I, and 10 in the Group II) were unable to complete this test because of other injuries, pain, or pregnancy. Testing isokinetic strength and measuring thigh atrophy showed that there were no significant differences between the two groups.

7.1.3. Final evaluation of the knee by the IKDC, Lysholm and Marshall scores

In the Group I, there were 14 normal knees (29%), 25 nearly normal knees (52%), and nine abnormal knees (19%) according to the final evaluation of the knee by the IKDC rating system. In the Group II, there were seven normal knees (16%), 27 nearly normal knees (63%), seven abnormal knees (16%), and two severely abnormal knees (5%) (NS).

The mean Lysholm score was 84 (SD 18, range 28-100) in the Group I and 79 (SD 18, range 33-100) in the Group II (NS). Respectively, the mean Marshall score was 43 (SD 5, range 30-49) in the Group I and 41 (SD 5, range 30-50) in the Group II (NS).

7.1.4. Ability to return to sports

Nine of the 101 patients (three in the Group I and six in the Group II) had had no sport activities before the injury. Among the remaining 49 patients (one lacking information) in the Group I, 44 subjects (90 %) could return to the preinjury level of sports while in the remaining 39 patients (information lacking in 3 cases) in the Group II, 31 subjects (79 %) could do the same (NS).

7.2. Study II

7.2.1. Anterior knee pain

After the follow-up, there were, according to the IKDC classification, 40 patients (44%) (27 men and 13 women) without anterior knee pain, 47 patients (52%) (34 men and 13 women) with a mild anterior knee pain (pain when kneeling), and four patients (4%) (two men and two women) with a moderate anterior knee pain (irritation also at rest). None was classified as suffering from severe anterior knee pain. Gender, age and weight had no significant association with anterior knee pain. Also, the follow-up time was the same in all groups. However, the time between the injury and the reconstruction was shortest in patients with mild anterior knee pain (1.1 years), when comparing in with patients without anterior knee pain (2.0 years), and those with a moderate anterior knee pain (7.2 years) (p=0.006).

7.2.2. Quadriceps torque deficit of the operated limb

In the isokinetic test of muscle strength, the operated limb in the patients without anterior knee pain showed an average 6 % deficit in extension at the speed of 60 degrees per second compared to the contralateral limb. In flexion, there was not side-to-side difference. At 180 degrees per second, the extension strength deficit was 3 % and again flexion strengths were equal. At 240 degrees per second, the extension strength deficit was also 3 % and flexion strengths were equal.

In the patients with mild anterior knee pain, the average extension strength deficit was 13 % at the speed of 60 degrees per second compared to the contralateral limb. Flexion strengths were again equal. At 180 degrees per second, the corresponding numbers were 7 % and 0 %. At 240 degrees per second, the numbers were 8 % and 4 %, respectively.

In the patients with moderate anterior knee pain, the average extension strength deficit was 24 % at the speed of 60 degrees per second compared to contralateral limb. In flexion, the strength deficit was 5 %. At 180 degrees per second, the corresponding numbers were 13 % and 5 %. At 240 degrees per second, the numbers were 12 % and 5 %, respectively. The group difference was significant in extension at the speed of 60 degrees per second (p=0.014) (Study II: Table 2).

7.2.3. Association between the anterior knee pain and the clinical outcome

According to the final evaluation of the IKDC rating scale, 12 patients (30%) had normal knees, 25 patients (63%) nearly normal knees, and three patients (7%) abnormal knees in the patients without anterior knee pain. In the patients with mild anterior knee pain, the corresponding numbers were nine (19%), 25 (53%), and 12 (26%). Furthermore one patient (2%) had severely abnormal knee. Among the four patients with moderate anterior knee pain, there were two nearly normal knees (50%), one abnormal knee (25%), and one severely abnormal knee (25%). The difference between subgroups was significant (p=0.01).

The mean Lysholm score was 92 (range, 45-100) in patients without anterior knee pain, 85 (range, 28-100) in patients with mild anterior knee pain, and 80 (range, 73-89) in patients with moderate anterior knee pain. The corresponding numbers were 45 (range, 35-50), 41 (range, 30-49), and 40 (range, 30-43) in the Marshall score. The best result was in the patients without anterior knee pain according to both Lysholm (p=0.013) and Marshall (p=0.003) knee scores.

Subjective overall assessment, as determined by the patient him/herself, was best in patients without anterior knee pain (p=0.002). Similar result was also found in the symptom evaluation of the knee (p=0.007) (Study II: Table 7). Knee extension (as compared to the other side) was better in patients without anterior knee pain than in those with anterior knee pain (p<0.001). The same applied to knee flexion (p=0.025) (Study II: Table 5). There were no significant differences between the subgroups of patients relative to the stability of the knee, and only 2 patients of all had an unstable knee (Study II: Table 6).

In the functional tests of the knee, the single-legged hop test for distance showed no significant differences between the subgroups. Three patients had difficulties going downstairs overall. Two of them had mild anterior knee pain, and one had moderate anterior knee pain. Two patients had difficulties going upstairs, and both of them had moderate anterior knee pain. The differences with the difficulties in the stairs between the subgroups were significant (p<0.05).

Patellofemoral and medial tibiofemoral osteoarthritis showed no significant differences between the subgroups, otherwise lateral tibiofemoral osteoarthritis did. Only two patients (5%) without anterior knee pain had mild degenerative changes in the lateral tibiofemoral joint. In the patients with mild anterior knee pain, five patients (11%) had mild and one patient (2%) had moderate degenerative changes, respectively. Among the four patients with moderate anterior knee pain, one patient (25%) had moderate degenerative changes in the lateral tibiofemoral knee joint ($p=0.021$).

7.2.4. Logistic regression analysis for anterior knee pain

In the logistic forward-stepping regression analysis, the knee extension strength deficit at the speed of 60 degrees per second was the only significant ($r=0.154$, $p=0.028$) variable to predict anterior knee pain. Other objective measurements of the knee (flexion strength deficit, range of motion, stability, and radiographs) did not correlate significantly with the outcome.

7.3. Study III

7.3.1. Degenerative changes in the patellofemoral and tibiofemoral joints

At the follow-up, the radiographs showed that 53 patients (53%) (35 men and 18 women) had no signs of patellofemoral osteoarthritis (named Group I), while in the remaining 47 patients (47%) such changes were seen. Of these 47 patients, 34 patients (34% of the entire patient population) (24 men and 10 women) showed mild degenerative changes (named Group II), 12 patients (12%) (11 men and one women) moderate degenerative changes, and one woman severe degenerative changes (moderate and severe changes named as Group III).

In the lateral tibiofemoral joint, 86 patients (86%) had no degenerative changes, while ten patients (10%) had mild, and four patients (4%) moderate degenerative changes. In the medial tibiofemoral joint, the corresponding numbers were 82 (82%), 14 (14%), and four (4%).

7.3.2. Shortening of the patellar tendon after the ACL reconstruction and its relationship to patellofemoral osteoarthritis

The average shortening of the patellar tendon was 2.4 mm (SD 4.3 mm) in the Group I, 3.9 mm (SD 5.3 mm) in the Group II, and 6.8 mm (SD 7.8 mm) in the Group III ($p<0.05$). The average lengthening of the patella was not significant between the groups (Study III: Table 1). The mean Insall-Salvati index (Insall and Salvati 1971) was the same in every group before the reconstruction

(1.04, SD 0.1). At the follow-up, the mean Insall-Salvati index was 0.95 (SD 0.1) in the Group I, 0.93 (SD 0.1) in the Group II, and 0.86 (SD 0.1) in the Group III ($p<0.05$).

7.3.3. Association between the patellofemoral osteoarthritis and the clinical outcome

According to the IKDC rating scale, 13 patients (25 %) in the Group I had normal knees, 34 patients (64 %) nearly normal knees, and six patients (11 %) abnormal knees. The corresponding figures were ten (29 %), 16 (47 %), and eight (24 %) in the Group II. In the Group III, there were no normal knees, but six (46 %) nearly normal knees, five (39 %) abnormal knees, and two (15 %) severely abnormal knees ($p<0.001$).

The mean Lysholm score was 88 (SD 12) in the Group I, 79 (SD 20) in the Group II, and 65 (SD 20) in the Group III. The corresponding numbers were 44 (SD 3), 42 (SD 5), and 37 (SD 5) in the Marshall score. The best result was in the Group I and the worst result in the Group III. The differences between the groups were significant according to the both Lysholm and Marshall knee scores ($p<0.001$).

Subjectively, 25 patients (47 %) in the Group I considered their knees normal, 24 (45 %) nearly normal, and four (8 %) abnormal. The corresponding numbers were 14 (41 %), 16 (47 %), and four (12 %) in the Group II, and one (8 %), eight (61 %), and four (31 %) in the Group III ($p<0.05$). In the symptom evaluation of the knee, the group difference was not significant.

The outcome of the objective tests are summarized in Study III in Table 4. The range of motion was better in patients without patellofemoral osteoarthritis than in patients with patellofemoral osteoarthritis ($p<0.001$). Only three patients (2 in the Group I, and 1 in the Group III) had an unstable knee overall, and the group difference was not significant. Patellofemoral crepitation was significantly more common in patients with patellofemoral osteoarthritis than without it ($p<0.001$). However, in the presence of anterior knee pain, there was no subgroup difference. The same applied also the single-legged hop test.

In the isokinetic test of muscle strength, the operated limb of the Group I patients showed an average 8 % deficit in extension at the speed of 60 degrees per second. In flexion, there was not any side-to-side difference. At 180 degrees per second, the extension strength deficit was 4 % and again the flexion strengths were equal. At 240 degrees per second, the corresponding numbers were 5 % and 2 %. In the Group II, these numbers were 8 % and 0 % at the speed of 60 degrees per second, 3 % and 0 % at the speed of 180 degrees per second, and 3 % and 2 % at the speed of 240 degrees per second, respectively. In the Group III, the similar numbers were 26 % and 6 % at the speed of 60 degrees per second, 13 % and 4 % at the speed of 180 degrees per second, and 11 % and 2 % at the speed of 240 degrees per second, respectively. The group difference was significant in extension at the speed of 60 degrees per second ($p<0.001$) and at the speed of 180 degrees per second ($p=0.045$).

7.4. Study IV

7.4.1. The sum score of the graft placement and its relationship to the clinical outcome

In the studied patients, the average femoral tunnel placement of the graft, as measured from the ”junction reference point”, was +1.8 mm (SD 7.0 mm). When measuring from the posterior surface of the femoral condyle and reporting as a percentage from the entire length of the femoral condyle, the average placement of the femoral tunnel of the graft was 36.5 % (SD 11.1%). The average placement of the tibial tunnel of the graft, as measured from the anterior corner of the tibial plateau and reported as a percentage of the entire tibial plateau, was 24.5 % (SD 6.8 %). The average sum score of the graft placement was 61.1 (SD 13.1).

The relationship between the range of motion of the knee and graft placement was not statistically significant in any methods used for measurements of the graft placement (Study IV: Table1). However, ”the sum score of the graft placement” tended to be smaller in patients with a normal range of motion of the knee than in patients with an abnormal range of motion of the knee (Table VI).

In this study, only three patients had an unstable knee, so the graft placement difference could not be reliably evaluated between patients with a stable or unstable knee.

The relationship between the graft placement and the medial tibiofemoral osteoarthritis of the injured knee was not significant in any methods used for measurements of the graft placement (Study IV: Table 3). Similar result was also between the graft placement and the lateral tibiofemoral osteoarthritis (Study IV: Table 4). However, ”the sum score of the graft placement” tended to be smaller in patients without medial or lateral tibiofemoral osteoarthritis than patients with medial or lateral tibiofemoral osteoarthritis (Table VI).

Table VI. The sum score of the graft placement and its relatioship to the range of motion, stability, medial and lateral tibiofemoral osteoarthritis (OA), patellofemoral osteoarthritis (OA), and the final evaluation of the knee by the IKDC rating system. Mean (SD).

	The sum score of the graft placement				
IKDC evaluation	normal	nearly normal	abnormal	severely abnormal	significance
range of motion	59.2 (13.4)	63.9 (12.9)	64.8 (10.5)	66.0 (8.5)	NS
stability	62.0 (14.5)	58.7 (8.2)	58.0 (3.0)	-	NS
tibiofemoral OA					
medial	60.5 (13.6)	61.5 (6.7)	70.3 (18.5)	-	NS
lateral	60.7 (13.0)	61.2 (11.5)	67.5 (19.8)	-	NS
patellofemoral OA	59.6 (13.2)	62.3 (13.2)	61.0 (8.3)	97.0	p=0.033
final evaluation	61.9 (17.5)	59.8 (11.5)	63.2 (12.1)	66.0 (8.5)	NS

SD= standard deviation
NS= not significant

The relationship between ”the sum score of the graft placement” and patellofemoral osteoarthritis was significant (p=0.033), so that ”the sum score of the graft placement” was smaller (better) in patients without patellofemoral osteoarthritis than in patients with patellofemoral osteoarthritis (Table VI). Average of ”the sum score of the graft placement” was 59.6 (SD 13.2) in the 53 patients without patellofemoral osteoarthritis, 62.3 (SD 13.2) in the 34 patients with mild patellofemoral osteoarthritis, 61.0 in the 12 patients with moderate patellofemoral osteoarthritis, and 97.0 in the one patient with severe patellofemoral osteoarthritis (Study III: Figure 1).

In the correlation analysis, correlations between the ”junction reference point” and the Lysholm and the Marshall knee scores were not significant. Neither was the correlation between the placement of femoral or tibial tunnel and the Lysholm and the Marshall knee scores. However, the correlation between ”the sum score of the graft placement” and the Lysholm knee score was significant (r= -0.244, p= 0.015), and the same concerned correlation between ”the sum score of the graft placement” and the Marshall knee score (r= -0.244, p= 0.015). This indicated that ”the sum score of the graft placement” was smaller or biomechanically more optimal in patients with good Lysholm and Marshall knee scores than in patients with poorer knee scores. In other words, the more horizontal the graft position was the better were the clinical knee scores, and vice versa.

In the final evaluation of the knee by the IKDC rating system, the average of ”the sum score of the graft placement” was 61.9 (SD 17.5) in the 23 patients with ”normal” outcome, 59.8 (SD 11.5) in the 56 patients with ”nearly normal” outcome, 63.2 (SD 12.1) in the 19 patients with ”abnormal” outcome, and 66.0 (SD 8.5) in the patients with ”severely abnormal” outcome (Table VI) (NS).

7.5. Study V

7.5.1. The clinical outcome of the ACL reconstruction in patients with or without accompanying injuries

Subjectively, 68 patients were satisfied with their knees and only four patients (two from both groups) considered their knees ”abnormal”. The majority of the patients recognized no (44 patients, 61 %) or only little (23 patients, 32 %) pain, swelling or giving way in the reconstructed knee. Only five patients (two from the group A with an isolated ACL tear, and three from the group B with an ACL tear with accompanying injuries) had so much symptoms in their knee that it was recorded as ”abnormal”. The group difference was not significant.

In the final evaluation with the IKDC rating system, only ten patients (five from each group) were evaluated as ”abnormal” and no-one as ”severely abnormal”. This means that 62 patients (86%) had satisfactory final outcome. The group difference was not significant (Study V: Table 2). The mean Lysholm score was 86 (SD 16) in the group A and 83 (SD 17) in the group B. Corresponding figures were 43 (SD 4) and 42 (SD 5) in the Marshall knee score. Both scores were slightly better in the group A than group B, but the differences were so small that the group differences were not significant (Study V: Table 3).

Range of motion of the knee was satisfactory (”normal” or ”nearly normal”) in 30 patients (88 %) in the group A, and 36 patients (95%) in the group B (NS) (Study V: Table 4). Stability of the knee was ”normal” in 27 patients (79%), and ”nearly normal” in seven patients (21%) in the group A, while these figures were 29 (76%), and nine (24%) in the group B (NS) (Study V: Table 5). So, all the knees were stable at the follow-up.

In the single-legged hop test only one patient had an ”abnormal” result (the patient was in the group B). The group difference was not significant. Testing isokinetic strength and measuring thigh atrophy showed also that there were no significant differences between the two groups.

Degenerative changes in the lateral tibiofemoral compartment of the injured knee were rare. There were only three patients (two in the group A and one in the group B), who had degenerative changes of the lateral compartment, and all these changes were mild. In the medial tibiofemoral compartment, seven patients (five in the group A and two in the group B) had degenerative changes, and also these changes were mild. The group difference was not significant in either on the lateral or medial side. In the patellofemoral compartment, 27 patients (38%) had mild, and five (7%) moderate degenerative changes, and again the group difference was not significant.

The group A patients with an isolated ACL tear were on an average 14 (SD 7) weeks in the sick-leave after the ACL reconstruction. This time was 19 (SD 17) weeks in the group B (p=0.096). Of the 72 patients reexamined, seven (three in the group A and four in the group B) had no sports habbits before the injury. Among the remaining 31 patients in the group A, 28 (90%) returned to their pre-injury level of sporting activity, while in the remaining 34 patients in the group B, 28 (82%) could do the same (NS).

During the follow-up, only four additional knee procedures had to be done in the group A (isolated ACL tear), while this number was 18 in the group B (ACL tear with accompanying injuries) (p=0.034) (Study V: Table 6). Knee manipulations and arthroscopic divisions of adhesions (n=13) were done during the rehabilitation period, if the range of motion of the reconstructed knee remained unsatisfactory (on an average 4 months after the ACL reconstruction, range 3-6 months). Also, one removal of the screws was done during this period (because of infection). The remaining procedures (arthroscopic partial meniscectomies and diagnostic arthroscopies) (n=8) were done later on because of a new knee injury (on an average 2.5 years after the ACL reconstruction, range 1.0-3.5 years), thus leading to another sick-leave (on an average 2 weeks, range 1-3 weeks).

8. GENERAL DISCUSSION

8.1. The reliability of the ACL reconstruction with a BTB autograft

The BTB autograft has shown the most predictable long-term results in the ACL surgery (Shelbourne et al. 1990, Shelbourne and Gray 1997), and therefore this reconstruction has been often regarded as the golden standard procedure (Fu and Schulte 1996, Järvinen et al. 1995, Renström 1991, Shelbourne and Gray 1997). The fixation of the BTB graft is rigid with its attached bony ends providing good mechanical strength of the graft (Aglietti et al. 1994, Muneta et al. 1998, Shelbourne et al. 1995, Roos and Karlsson 1998), and becuse of that, it allows the earliest return to high-demand activities (Fu et al. 2000).

In our study, nearly 90 % of the patients considered subjectively their knees normal or nearly normal 5 to 9 years after the surgery according to the IKDC standard knee ligament evaluation form. Also, in the final evaluation of the knee with the IKDC rating system at the follow-up, 80 % of our patients achieved satisfactory (normal or nearly normal) results. These results are comparable with many previous studies (Al-Zarahini et al. 1997, Bach et al. 1998, Marcacci et al. 1995, Mitsou and Vallianatos 1996, Noyes and Barber-Westin 1997, Shelbourne and Gray 1997, Otto et al. 1998). Also, the range of motion and the stability of the knee of our patients were good. The range of motion of the knee was satisfactory in over 90 % of the patients, and only three patients of all had clear instability of the knee at the follow-up. One of these three patients needed a re-reconstruction of the ACL, while the other two patients (despite instability) continued playing soccer and were satisfied with their knees. Recently, Otto et al. (1998) reported as good 5-year stability results as we did in our study. In their study, the reconstruction was done arthroscopically.

One reason for the ACL reconstruction has been said to be prevention of later-life degenerative changes of the knee joint (Jomha et al. 1999). In our study, 14 % of the patients had some degenerative changes in the lateral tibiofemoral joint and 18 % in the medial tibiofemoral joint, while almost half of the patients had some degenerative changes and crepitation in the patellofemoral joint. The changes were, however, mild in most of the subjects and only one patient experienced pain and crepitation of the patellofemoral joint at the follow-up. These rather encouraging 5- to 9- year results showed that the ACL reconstructions succeeded quite well to prevent the degenerative changes of the tibiofemoral joint, but not of those seen in the patellofemoral joint. However, only the following years will show the final incidence of postoperative osteoarthritis among patients with an ACL reconstruction.

8.2. Timing of the ACL reconstruction

The optimal time for the early-phase ACL reconstruction has been a somewhat controversial issue. Some studies have suggested that the procedure should not be done during the very first weeks after the injury because of an increased risk for arthrofibrosis (Shelbourne et al. 1991), while other studies have found no difficulties in obtaining a full range of motion of the knee after early ACL reconstruction (Majors and Woodfin 1996, Noyes and Barber-Westin 1997).

This study demonstrated that a middle-third BTB autograft is effective for reconstruction of an acutely ruptured as well as chronically insufficient ACL. However, the patients with early reconstruction were more satisfied with their knees than the patients with late reconstruction. Also the former patients had less pain and functional limitations and could return to more strenuous athletic activities than those with the late reconstruction. As such, these findings were not surprising, because patients with late reconstruction had suffered from pain, giving way and instability-induced degenerative changes for an average of nearly four years before the reconstruction, and the number of previous surgical procedures was also significantly higher in this group of patients than in those with an acute phase reconstruction. Noyes and Barber-Westin (1997) received same kind of results, and recommended the early ACL reconstruction (less than 3 months after the injury) for active persons.

The above noted findings thus support the concept that the ACL reconstruction needs to be done before degenerative changes of the knee develop and this may best concern athletically active persons. In fact, the concept of reconstruction in the acute phase has become popular in some centers in central Europe, especially in the alpine countries, with good results. In this study, some of the patients with early ACL reconstruction had had postoperatively contraction problems in the knee joint so that postoperatively nine of these patients underwent knee manipulation under anesthesia or divisions of adhesions. As noted above, Shelbourne et al. (1991) have also reported that arthrofibrosis of the knee may become a problem after acute-phase ACL reconstruction. The brace we used after the reconstruction, compared to the accelerated rehabilitation used by Shelbourne and

Gray (1997), probably caused some of the postoperative problems we saw in the knee flexion and extension. Today, brace immobilization after ACL reconstruction is no longer used in our hospital.

8.3. Problems following the ACL reconstruction with a BTB autograft

The most common problems following the ACL reconstruction with the BTB autograft are anterior knee pain, patellofemoral osteoarthritis, delayed recovery of the knee extension strength, and incomplete range of motion of the knee (Rosenberg et al. 1992, Aglietti et al. 1993, Aglietti et al. 1994, Natri et al. 1996, Shelbourne and Trumper 1997, Stapleton 1997, Kartus et al. 1999). These problems can not be separated from each other, because they create a kind of vicious circle with a strict relationship to each other. Also in our study, these problems were present and are discussed in detail below.

8.3.1. Anterior knee pain

One of the major problems with the patellar tendon autograft procedures is the postoperative anterior knee pain (Sachs et al. 1989, Shelbourne et al. 1991, Rosenberg et al. 1992, Kleinpol et al. 1994, Rubinstein et al. 1994, Shelbourne and Trumper 1997, Kartus et al. 1997, Stapleton 1997, Bach et al. 1998, Kartus et al. 1999). In our study, about half of the patients had mild anterior knee pain at the follow-up, and in 4 % of the patients the pain was moderate. Shelbourne and Trumper (1997) suggested that the extension deficit of the knee is the main reason for the anterior knee pain and thus recommended that immediately after the surgery full knee extension should be allowed. Our patients´ knees were fixed in a brace for two weeks (35 degrees flexion) and were then allowed to move from 30 to 60 degrees. Full movement was not allowed until five to seven weeks postoperatively. If the full extension of the knee immediately after the reconstruction indeed prevents appearance of postoperative anterior knee pain, our current treatment protocol without brace and movement limitations should further improve our overall results.

In this study, according to the logistic regression analysis for the predicting factors of the anterior knee pain, the extension torque deficit of the ACL-reconstructed knee was the most important factor associated with anterior knee pain. Many previous studies have shown that an ACL-reconstructed knee with a BTB autograft often has extension torque deficit (Rosenberg et al. 1992, Järvinen et al. 1995, Natri et al. 1996, Muneta et al. 1998, Österås et al. 1998), and therefore, great emphasis has been paid to find out the most efficient methods of strengthening the muscles without damaging the reconstructed ACL graft (Antopoulos and Gillquist 1996, Donatelli et al. 1996). With hamstring grafts, strength deficit seems to be smaller (Ohkoshi et al. 1998). However, the muscle strength during knee flexion is a composite of the coordinated movement of various muscles, including the biceps muscle of the thigh, the semimembranosus muscle, the semitendinosus muscle, and the gracilis muscle, and accordingly, it is difficult to analyze the properties of the individual flexor muscles (Ohkoshi et al. 1998).

One of our patients had 80 % isokinetic extension torque deficit in the index knee at the speed of 60 degrees per second, and she also had moderate anterior knee pain. We gave her a special program to improve the quadriceps performance, and after six months the extension torque deficit was only 20 % and the anterior knee pain was absent. This case refers to the possibility that at least in some patients the extension torque deficit is a true causal factor of the anterior knee pain, and thus treatable. In this respect, encouraging results have been recently obtained by using intense quadriceps-muscle exercises in chronic patellofemoral pain syndrome (Kannus et al. 1999).

Optimal function following ACL reconstruction is dependent on many factors, of which muscle strength is one. Any loss of strength may result in decreased dynamic stability of the knee and place a greater reliance on the passive restraints of the knee (Strauss et al. 1998). However, in our study, the stability of the knee showed no clear association with anterior knee pain, although the extension strength deficit did. This may be partly due to the fact that there were only few patients with an unstable knee. Also, the single-legged hop test for distance showed no difference between the groups. However, nine of the 14 patients, who were not able to do this test, had anterior knee pain. Nevertheless, Paterno and Greenberger (1996) have shown that the single-legged hop test for distance is reliable test for both young adults with healthy knees and those who have had ACL reconstruction. They also concluded that this test may aid clinicians in determining whether patients are ready to return to prior level of activity.

The Lysholm (Lysholm and Gillquist 1982) and the Marshall (Marshall et al. 1977) knee scores were significantly lower in patients with anterior knee pain than in patients without it. Similar results were found in the final evaluation of the IKDC rating scale. These results are in line with previous studies (Otto et al. 1998). Also, the patients without anterior knee pain were subjectively more often satisfied with the knee and had less swelling or giving way symptoms of the knee than the patients with anterior knee pain. These findings indicate that anterior knee pain (its absence or occurrence) is one of the most essential parts of evaluation when assessing the long-term outcome of an ACL reconstruction.

In the patients without anterior knee pain, the range of motion of the knee (especially the knee extension) was better than in the patients with anterior knee pain, although in this respect there was no statistical group difference in the logistic regression analysis. Kartus et al. (1999) reported recently a similar result in their 2 to 5-year follow-up study of 604 patients. They have also shown in another study of Cadaveric knee dissection (Kartus et al. 1999) and magnetic resonance imaging (MRI) study (Kartus et al. 1999) that one of the main reasons for the anterior knee pain is the damage of the infrapatellar nerves in the graft-harvesting. They concluded that the subcutaneous graft-harvesting technique produced significantly less disturbance in anterior knee sensitivity and a significantly smaller residual donor-site gap, compared with the traditional technique. In our patients, the miniarthrotomy technique was used for the ACL reconstruction, and maybe some damage of the infrapatellar nerves occurred.

8.3.2. Patellofemoral osteoarthritis

In the literature, several authors have reported patellofemoral problems, such as crepitation, pain, and limitations in the range of motion of the knee, after an ACL reconstruction (Aglietti et al. 1993, Aglietti et al. 1994, Breitfuss et al. 1996, Majors and Woodfin 1996, Rosenberg et al. 1992, Sachs et al. 1989). Rosenberg et al. (1992) reported that half of their patients had abnormal patellar signs in radiographic evaluation and that the effect of the procedure on the extensor mechanism of the knee was also significant. However, their study had only ten patients.

Our study showed that degenerative changes of the patellofemoral joint were very common on an average 7 years after an anterior cruciate ligament reconstruction with the bone-patellar tendon-bone autograft. Almost half of our patients had mild or moderate degenerative changes in the patellofemoral joint (IKDC), and the correlation to the patellofemoral crepitation was significant. However, it was somewhat surprising that the correlation between patellofemoral osteoarthritis and anterior knee pain was not significant.

According to this study, the shortening of the patellar tendon seems to correlate to the severity of the patellofemoral osteoarthritis. The closure of the patellar tendon defect after harvesting a middle-third of it in all of our patients might have had some influence to the shortening of the residual patellar tendon. Therefore, we have now abandoned the closure of the patellar tendon defect in the ACL surgery when using the BTB autograft. Also, the miniarthrotomy technique, which was used with these patients, is traumatic in relation to the infrapatellar fat pad and the infrapatellar bursa. That might have played a role when considering the amount of patellar tendon shortening occurred in our patients. The surgical technique we currently use is an arthroscopic ACL reconstruction. The coming years will show whether these changes in our surgical procedure can reduce the shortening of the patellar tendon and the incidence of development of patellofemoral osteoarthritis after ACL reconstruction.

Breitfuss et al. (1996) observed that shortening of the patellar tendon influenced on the biomechanics of the patellofemoral joint, although in their study only 25 % of patients had degenerative changes in the patellofemoral joint. In the present study, the Insall-Salvati (Insall and Salvati 1971) index was significantly lower in patients with degenerative changes in the patellofemoral joint than in those without patellofemoral osteoarthritis. Berg et al. (1996) compared four measurement methods of patellar height and concluded that patellar height-ratio changes greater than 0.06 represent a true change in the patellar height. In our study, the changes in the Insall-Salvati index exceeded this value.

According to this study, Lysholm and Marshall knee scores were significantly lower in patients with patellofemoral osteoarthritis than in patients without it. Similar results were found in the final evaluation of the IKDC rating scale. The patients without patellofemoral osteoarthritis were subjectively more often satisfied with the index knee and had less pain and swelling in the knee joint than the patients with patellofemoral osteoarthritis. Also, the range of motion of the knee was significantly better in patients without the patellofemoral osteoarthritis than in those with this complaint. The single-legged hop test and the ligamentous stability of the knee had no correlation to patellofemoral osteoarthritis. On the other hand, only three of our patients had an unstable knee.

In our study, the isokinetic testing showed quadriceps strength deficit of 26 % (mean) at the speed of 60 degrees per second in patients with moderate or severe patellofemoral osteoarthritis, while in the other patients groups this deficit was significantly lower (8%). Rosenberg et al. (1992) reported quadriceps strength deficit of 18 % (mean) in patients with ACL reconstruction, but they did not correlate the findings to the occurrence of patellofemoral osteoarthritis.

8.4. Graft placement

An important aspect in the ACL reconstruction is the placement of the graft. The aim of the reconstruction is to identify the ideal position for graft placement to exactly reproduce the anatomy and function of an intact ACL. Previously, isometric placement of the ACL graft was favored (Hefzy et al. 1989). However, the concept of isometry is now considered oversimplified, as recent basic science studies have shown that a normal ACL is not an isometric structure (Fu et al.1999). Instead, the various fiber bundles of the ACL are under variable stress during knee motion (Furman et al. 1976).

Tunnel positioning, as measured from lateral radiograph, is considered the best predictor of the clinical stability of the reconstructed knee (Recht et al. 1996, Khalfayan et al. 1996). However, some studies have shown that postoperative radiograph may not be a sufficient tool for assessing the graft placement (Klos et al. 1999). The reason for the difficulties with tunnel measurements seems to be in different locations of the reference points (Draganich et al.1996). Khalfayan et al. (1996) have stated that the optimal positioning of the femoral tunnel is more than 60 % from anterior to posterior direction (in a lateral radiograph) along Blumensaat`s line (i.e. less than 40 % for our measurements), while according to Recht et al. (1996), the optimal placement of the femoral tunnel is in the intersection of the intercondylar roof (Blumensaat`s line) and a line representing the posterior femoral cortex (which is the ”junction reference point” in our study). So in this study, we actually used two different reference points for the evaluation of the femoral tunnel placement of the graft, and, according to both of these methods, our average tunnel placement was good.

In our study, tibial tunnel placement of the graft did not show any significant effect to the range of motion of the knee, unlike Howell and Clark (1992) previous reported. However, in our new evaluation method, ”the sum score of the graft placement” tended to be smaller in patients with normal range of motion of the injured knee than in patients with abnormal range of motion of the knee. In this study, only three patients had an unstable knee, so the relationship between the stability of the injured knee and the graft placement could not be well studied.

According to this study, the relationship between osteoarthritic changes in the tibiofemoral joint and the graft placement was not statistically significant in any methods used for the measurements. However, ”the sum score of the graft placement” tended to be smaller in patients without tibiofemoral osteoarthritis than in patients with tibiofemoral osteoarthritis. The difference was actually quite large between the patients without osteoarthritis and with a moderate osteoarthritis, but because only four patients had a moderate osteoarthritis in the tibiofemoral joint of the knee, the difference was not statistically significant. In addition,”the sum score of the graft placement” was significantly smaller in patients without patellofemoral osteoarthritis than in patients with patellofemoral osteoarthritis ($p=0.033$).

In our study, correlation between the clinical Lysholm and Marshall knee scores and ”the sum score of the graft placement” was significant, while the separate measurements of the graft placement had not significant correlation to the clinical knee scores. The optimal IKDC evaluation score (normal or nearly normal) was obtained, when the”sum score of the graft placement” was 59 to 62. However, it must be kept in mind that this value could vary because the anatomy of the knee was not the same in every knee. The intercondylar roof could be in the different angle in different patients, as shown in the study of Buzzi et al. (1999), and a notchplasty was also performed (the intercondylar space could also vary). If the femoral tunnel was, for example, 5 % too anterior from the optimal placement, and the tibial tunnel also 5 % too anterior from the optimal placement, ”the sum score of the graft placement ” would still be the same as in the optimal placement. So, in theory, when thinking separately the femoral and tibial tunnel placements, this kind of patient should have an unstable knee with too anterior femoral tunnel placement of the graft, and an impingement of the knee with too anterior tibial placement of the graft. But, on the contrary, in this study this kind of patient had a comparable result to that of the most isometric placement of the entire graft. In our material, the smallest ”sum score of the graft placement” was 35 (indicating that the tibial tunnel was clearly anterior and the femoral tunnel clearly posterior, and thus the entire graft very horisontal), and this particular patient had a stable knee with a normal range of motion of the knee and received 100 points in the Lysholm score. Recently, other studies have also found that the graft placement needs to be customized in each knee at the time of surgery, and that the most isometric graft placement is perhaps not always the best (Draganich et al. 1999, Fu et al. 1999, Howell et al. 1999).

8.5. ACL reconstruction with or without accompanying injuries

Our study showed that 5-9 years after the ACL reconstruction with BTB autograft, clinical and radiological results were about the same, whether or not the primary ACL injury was combined with other injuries. The only significant difference was that in the group with an ACL tear and accompanying injuries there were more subsequent knee procedures than in the group with an isolated ACL tear only. Lundberg and Messner (1997) have also found in their matched 10-year comparison study of an isolated MCL rupture and a combined MCL-ACL rupture that patients with combined MCL ruptures had more reinjuries and repeat surgeries than those with an isolated MCL injury. In their study, radiographic osteoarthritis was also more common in patients with combined ruptures.

Most patients in our study were satisfied with their knee; only four were unsatisfied.

Similar result was also found in symptoms such as pain, swelling, and giving way of the knee. It was somewhat surprising that the groups had not major differences at the follow-up, although in the patients with accompanying injuries, several partial or subtotal meniscectomies were done in the primary surgery, as well as afterwards. Schimmer et al. (1998) found in their 12-year follow-up study of partial meniscectomy, comparing the results with their earlier 4-year follow-up study, that the factor with the highest impact on long-term results was the damage to the articular cartilage. This damage did not influence knee function for several years, but became increasingly symptomatic over time, after 5 years and more. In our study, the mean follow-up time was 7 years, and still the patients were satisfied.

In this study, only few patients had limited range of motion of the knee, and the knees were stable. The good stability of the knees may be one reason, why the patients were so satisfied with their knee in both groups. Some studies have actually shown that an ACL reconstruction can improve the symptoms after cartilage damage and previously done meniscectomies, if the stability of the reconstructed knee is good (Barrett and Ruff 1997, Noyes and Barber-Westin 1997). Not surprisingly, Burks et al. (1997) have also found in their 15-year follow-up study of partial meniscectomy that stable knees with meniscectomies do better than unstable knees with meniscectomies.

In this study, the average of the Lysholm and the Marshall knee scores were good in both groups. In the group with an isolated ACL tear these scores tended to be better than in the group with an ACL tear with accompanying injuries, but the difference was not statistically significant. In the final evaluation of the IKDC, most of our patients achieved satisfactory results, and again both groups were equal. Overall, these results are comparable with previous results in the literature (Järvinen et al. 1995, Patel et al. 2000), although some studies have shown that combined knee injuries have poorer prognosis than the isolated ones (Kannus 1988, Lundberg and Messner 1997, Petersen and Laprell 1999).

In this study, tibiofemoral osteoarthritis was quite rare and mild. Somewhat surprisingly, the majority of the osteoarthritis was seen in the group with an isolated ACL tear, unlike Jomha et al. (1999) in their 7-year follow-up study, and Patel et al. (2000) in their 5-year follow-up study have recently reported. Several studies have concluded that partial or subtotal meniscectomy itself, with or without combined injuries, can lead to the osteoarthritis of the knee (Burks et al. 1997, Maletius and Messner 1996, Maletius and Messner 1999, Rangger et al. 1995, Schimmer et al. 1998). However, the shape, location and width of the meniscal tear also seem to have some effect to the cartilage damage of the knee (Cipolla et al. 1995, Fitzgibbons and Shelbourne 1995, Lewandrowski et al. 1997). Unfortunately, we do not have the primary intra-articular arthroscopic pictures from these knees, so we do not know exactly, what kind of tears the meniscal tears actually were. We only know that partial or subtotal meniscectomies were done to the 22 meniscal tears of this study. Rockborn and Gillquist (1996) have said that arthroscopic meniscectomy seems to be a benign operation regarding knee function and physical activity 13 years after subtotal or partial meniscectomies, and that more old than young patients have radiographic arthrosis after meniscectomy, and that these changes are more common after subtotal than more limited partial meniscectomy.

An ACL injury, especially when combined with other injuries, is a severe knee trauma. In our study, patients with accompanying injuries had to be out of their work almost five months postoperatively, while the patients with an isolated ACL tear only could return to their work after three and half months. Also, only 10 % of the patients with isolated ACL rupture could not return to their previous sports activity level, while this number was somewhat higher (18 %) in the patients with accompanying injuries.

8.6. Study limitations and the validity and reliability of the evaluation methods used

The current study series and its design have some limitations and they need consideration. First, this was a retrospective study series without any control group of either conservatively treated patients or some other reconstructive procedure (such as STG) of surgical treatment of the ruptured ACL. Second, 43 patients of the initial 144 patients were not able to attend the follow-up evaluation, and this could have some influence on our final result. However, 29 patients of these 43 patients could be contacted and interviewed with a questionnaire, and only 14 patients could not be contacted at all (one patient had died). Third, we did not have the primary intraarticular arthroscopic pictures from these knees (because we did not have this possibility ten years ago unlike today), and magnetic resonance imaging (MRI) was not performed at baseline or at the reexamination. With these patients, the AO screws (made from steel) were used in the fixation of the graft thus leading to many errors (artefacts) in postsurgical MRI evaluation, and therefore, we could not use the MRI at the reexamination. However, we analyzed preoperative, postoperative, and contralateral knee radiographs very carefully in all patients in this study.

Validity, as applied to data measurement, refers to the degree to which the measurement represents a true value. Reliability, on the other hand, refers to the ability of the researchers to reproduce or repeat the same measurements (Greenfield et al. 1998). The evaluation methods used in our study are generally considered valid and reliable (Holm et al. 1994, Myrer et al. 1996, Paterno and Greenberger 1996, Huber et al. 1997), although there has been some criticism concerning the knee scoring systems (Sgaglione et al. 1995, Höher et al. 1997), isokinetic muscle testing (Feiring and Ellenbecker 1996), and the postoperative measurements of the graft placement from the lateral radiograph (Klos et al. 1999). On the other hand, these methods are widely used after an ACL reconstruction and no clearly better evaluation methods have been developed and introduced. Our new method, ”the sum score of the graft placement”, of course, has not been used before. However, according to our present study, it seemed to be more accurate in evaluation of the postoperative graft placement than the methods described before.

9. CONCLUSIONS

1. Our results showed that an ACL reconstruction using a BTB autograft and miniarthrotomy technique leads, in general, to good ligamentous stability and function of the knee. It may also prevent the later-life degenerative changes of the tibiofemoral joint. However, about half of these patients had some knee problems, such as anterior knee pain and patellofemoral osteoarthritis, 5-9 years after the procedure.

2. Patients with an early ACL reconstruction were more satisfied with the end result, had less symptoms, and could return to sports activities more often than the patients with a late ACL reconstruction. Therefore, the surgery should be carried out before the onset of the late-phase symptoms (such as osteoarthritis), but probably not during the very first weeks after the injury because of the increased risk of adhesion formation and arthrofibrosis.

3. Mild anterior knee pain five to nine years after an ACL reconstruction with a BTB autograft was a rather common finding. This pain had a clear association with the subjective and clinical overall outcome. The most important factor related to occurrence of anterior knee pain was the extension torque deficit of the knee, and therefore, future sports medical studies should clarify whether improvement in quadriceps function could reduce the problem of postoperative anterior knee pain.

4. Our long-term follow-up showed that after an ACL reconstruction with a BTB autograft patellofemoral osteoarthritis occurs frequently, and has a clear association with the clinical outcome of the patient. The shortening of the patellar tendon correlated to the severity of the patellofemoral osteoarthritis so that greatest shortenings were seen in patients with most severe osteoarthritic changes, but further studies are needed to verify this finding and find out the main determinants of the shortening.

5. We developed a new evaluation method of graft placement after an ACL reconstruction, which takes into account both the femoral and the tibial positions of the graft simultaneously, and our study showed that ”the sum score of the graft placement” has an association to clinical outcome of patients and that it can better explain the long-term osteoarthritic changes at the injured knee than the separate measurements of the femoral and tibial tunnel placements. However, the optimal placement of the graft can vary from patient to patient because of the individual differencies in the anatomy of the knee and therefore an optimal position of the graft has to be decided individually at the surgery.

6. Our results showed that the differences in the follow-up results of patients with an isolated ACL tear versus those with an ACL tear with accompanying injuries were quite small five to nine years after the ACL reconstruction with a BTB autograft. This was true despite the fact that in the latter group many partial or subtotal meniscectomies and many primary repairs of MCL were done. Tibiofemoral osteoarthritis was quite rare, and this may partly be due to the fact that the ACL reconstructions were successful, so that the knees were stable at the follow-up. However, only the following years will show us the final outcome of the patients.

10. SUMMARY

The purpose of this study series was to present a long-term result of the anterior cruciate ligament (ACL) reconstruction with a bone-patellar tendon-bone (BTB) autograft with special emphasis on the timing of the reconstruction, and postoperative problems, such as anterior knee pain and patellofemoral osteoarthritis. We also introduced a new method to evaluate the graft placement. In addition, we compared the long-term results of the reconstruction in patients with isolated tear of the ACL to those with an ACL rupture with accompanying injuries.

The basic population of the study consisted of the 144 patients who underwent an ACL reconstruction (using the BTB autograft and miniarthrotomy technique) in the Tampere University Hospital between January 1989 and December 1991. Of these 144 patients, 130 (90%) patients could be contacted and interviewed with a questionnaire and 101 (70%) patients (70 men and 31 women) were able to attend the follow-up examination. The mean age of the patients at the time of the operation was 30.5 years (range, 15-61 years). The mean delay between the injury and the reconstruction was 1.7 years (range, 0-20 years), and the mean follow-up time was 6.9 years (range 4.6-8.8 years).

Clinical, functional and radiographic evaluation of the patients was performed using the standard knee ligament evaluation form of the International Knee Documentation Committee (IKDC), and the Lysholm and the Marshall knee scores. Also, the isokinetic muscle torque was measured, and the lengths of the patellar tendon and patella were measured from the lateral radiograph before the reconstruction and at the follow-up. In addition, the lateral radiograph of the knee was used in assessing the tunnels of the graft. The femoral tunnel placement was expressed as a percentage of the entire length of the femoral condyle from posterior-to-anterior along the Blumensaat`s line. The tibial tunnel placement was expressed as a percentage of the anterior-to-posterior length of the tibial plateau. To evaluate both the femoral and tibial tunnel placements simultaneously, we summed up the percentages of the femoral and the tibial tunnel placements thus ending up to a parameter called ”the sum score of the graft placement”.

According to the IKDC rating scale, 80 % of the patients had normal or nearly normal final outcome. The mean (standard deviation) Lysholm score (max. 100 points) was 82 (18) and the

mean Marshall score (max. 50 points) was 42 (5), and 98% of the patients had normal or nearly normal stability in the operated knee, as compared to contralateral knee. In none of these outcome parametres, there were significant differences between the early (within 6 weeks after the injury) and late reconstruction (more than 3 months after the injury) groups. However, patients with early reconstruction had less degenerative changes in the tibiofemoral joint, were subjectively more satisfied to the result, and could return to the pre-injury level of sports activities more often than the patients in the late reconstruction group.

About half of the patients had anterior knee pain, as classified by the IKDC. In the logistic regression analysis of predicting factors (forward-stepping), knee extension torque deficit of the operated limb was the only factor that showed significant association with anterior knee pain. Subjectively, the patients without anterior knee pain were more often satisfied with the overall outcome than the patients with anterior knee pain. Also, the Lysholm and Marshall knee scores and the final outcome in the IKDC rating scale were significantly better in patients without than with anterior knee pain.

Also, about half of the patients had patellofemoral osteoarthritis, and the shortening of the patellar tendon correlated to the severity of the patellofemoral osteoarthritis so that greatest shortenings were seen in patients with the most severe osteoarthritic changes. According to the IKDC, Lysholm and Marshall knee rating scales, the patients with patellofemoral osteoarthritis had worse final outcome than the patients without patellofemoral osteoarthritis.

The correlation between ”the sum score of the graft placement” and the Lysholm knee score was significant ($r= -0.244$, $p= 0.015$), the same concerned the correlation between ”the sum score of the graft placement” and the Marshall knee score ($r= -0.244$, $p= 0.015$). This indicated that ”the sum score of the graft placement” was smaller (biomechanically more optimal) in patients with good Lysholm and Marshall knee scores than in patients with poorer knee scores. ”The sum score of the graft placement” was also smaller in patients without patellofemoral osteoarthritis than in patients with patellofemoral osteoarthritis ($p=0.033$).

The differences between patients with an isolated ACL tear and those with an ACL tear with accompanying injuries were quite small. The final evaluation by the IKDC, and the Lysholm and the Marshall knee scores were similar in both groups, although there were significantly more often subsequent knee operations in the injured knee in the patients with accompanying knee injuries than in the patients with an isolated tear.

In conclusion, the stability of the knee was good after an ACL reconstruction with a BTB autograft, and therefore the tibiofemoral osteoarthritis was rare in both patients with early and late reconstruction, as well as those with an isolated tear of the ACL or with an ACL tear with accompanying injuries. However, about half of the patients had anterior knee pain and patellofemoral osteoarthritis with a significant extension strength deficit of the knee. Together these changes impaired the final outcome of the patients. It seems that harvesting of the middle part of the patellar tendon with traditional open technique, and with the closure of the defect with sutures in the patellar tendon, damage the extensor mechanism of the knee by shortening the patellar tendon thus leading to the degenerative changes of the patellofemoral joint. However, the graft placement had also significant correlation to the patellofemoral osteoarthritis, so that the patients with an incorrect placement of the graft had more patellofemoral osteoarthritis than the patients with a good graft placement.

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13. ORIGINAL PUBLICATIONS