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ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

with special reference to

magnetic resonance imaging
evaluation of the postoperative outcome

Academic Dissertation

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original studies, which are referred to in the text by their Roman numerals:


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ABBREVIATIONS AND DEFINITIONS

ACL = anterior cruciate ligament
AP = anteroposterior
BMDP = Bio-Medical Data Package
BTB = bone-(patellar) tendon-bone
CI = confidence interval
IKDC = International Knee Documentation Committee
MCL = medial collateral ligament
MRI = magnetic resonance imaging
ns = statistically non-significant
na = not available
PCL = posterior cruciate ligament
RCT = randomized controlled trial
SD = standard deviation
SE = spin echo
SI = signal intensity
SPSS = Statistical Product and Service Solutions
STG = semitendinosus-gracilis or hamstring tendons
STIR = short-inversion-time inversion-recovery or short tau inversion recovery
T1 = longitudinal relaxation time
T2 = transverse relaxation time
TE = time to echo
TI = inversion time
TR = repetition time
TSE = turbo spin echo
ABSTRACT

Anterior cruciate ligament (ACL) tear is a common sports injury of the knee. Arthroscopic reconstruction using autogenous graft material is widely used for patients with ACL instability. The grafts most commonly used are the patellar and the hamstring tendons, by various fixation techniques. Although clinical evaluation and conventional radiography are routinely used in follow-up after ACL surgery, magnetic resonance imaging (MRI) plays an important role in the diagnosis of complications after ACL surgery.

The aim of this thesis was to study the clinical outcome of patellar and hamstring tendon ACL reconstruction techniques. In addition, the postoperative appearance of the ACL graft was evaluated in several MRI sequences.

Of the 175 patients who underwent an arthroscopically assisted ACL reconstruction, 99 patients were randomized into patellar tendon (n=51) or hamstring tendon (n=48) groups. In addition, 62 patients with hamstring graft ACL reconstruction were randomized into either cross-pin (n=31) or interference screw (n=31) fixation groups. Outside the randomization protocol were 14 knees with symptomatic instability after patellar tendon ACL reconstruction.

Follow-up evaluation determined knee laxity and isokinetic muscle performance. In addition, the International Knee Documentation Committee’s forms, Lysholm knee score, Tegner activity level, and Kujala patellofemoral score forms were completed. Lateral and anteroposterior view radiographs were obtained. MRI was performed with a 1.5-T imager using a standard knee coil. Oblique sagittal and oblique coronal proton density-, T2-weighted and oblique sagittal STIR images, and oblique coronal pre- and postcontrast T1-weighted images were obtained. The appearance and enhancement pattern of the graft and periligamentous tissue, and the location of femoral and tibial bone tunnels were evaluated. After MRI, arthroscopy was performed on 14 symptomatic knees.

The results revealed no significant differences in the 2-year outcome between patellar and hamstring tendon graft, or cross-pin and interference screw fixation groups. In the hamstring tendon group, the average femoral and tibial bone tunnel diameter increased during 2 years follow-up by 33% and 23%, respectively. In the asymptomatic knees, the graft showed homogeneous and low signal intensity with periligamentous streaks of intermediate signal intensity on T2-weighted MR images. In the symptomatic knees, arthroscopy revealed 12 abnormal (11 lax and one torn) grafts and two meniscal tears, each with an intact graft. Among 3 lax grafts visible on arthroscopy, MRI showed an intact graft and improper bone tunnel placement. The graft itself did not enhance, but periligamentous tissues showed mild to moderate contrast enhancement.

For diagnosing graft failure, all MRI findings combined gave a specificity of 90% (95% confidence interval,
CI, 65-98%) and a sensitivity of 81% (95% CI, 61-92%).

In conclusion, all techniques appeared to improve patients' performance, and were therefore considered as good choices for ACL reconstruction. In follow-up, MRI permits direct evaluation of the ACL graft, the bone tunnels, and additional disorders of the knee. Bone tunnel enlargement and periligamentous tissue showing contrast enhancement were non-specific MRI findings that did not signify ACL deficiency. With an intact graft and optimal femoral bone tunnel placement, graft deficiency is unlikely, and the MRI examination should be carefully scrutinized for possible other causes for the patients’ symptoms.
INTRODUCTION

Surgical treatment of and techniques for ligamentous injuries in the knee have improved significantly over the past two decades. Today, arthroscopic reconstruction of the ACL with autogenous graft material is widely used for patients with anterior knee instability. The two most commonly used grafts are the central one-third of the patellar ligament (bone-tendon-bone, BTB) and the hamstring tendon (semitendinosus-gracilis, STG) construct (Herrington et al. 2005).

The reconstruction of ACL is a technically difficult procedure, and often failures can be attributed to surgical errors (Bealle et al. 1999). As many as 10% of patients may experience graft failure and recurrent instability (Wolf et al. 2002). The clinical outcome of ACL reconstruction is strongly correlated with a correct anatomical position of bone tunnels (Almekinders et al. 1998, Markolf et al. 2002).

Clinical evaluation and conventional radiography are used in routine follow-up after ACL reconstruction. However, as clinical manifestations of graft complications are often non-specific, and plain radiographs cannot directly visualize the graft and the adjacent soft tissues, an important tool in the diagnosis of complications after ACL reconstruction has been magnetic resonance imaging (MRI). State-of-the-art MRI offers excellent soft tissue contrast and spatial resolution (White et al. 2005). Contrast-enhanced MRI can provide additional information regarding the perfusion and vascularity of the ACL graft (Vogl et al. 2001).

First, this thesis reports the 2-year follow-up results of two RCTs comparing patellar and hamstring tendon techniques, and cross-pin and screw fixation techniques. Then, it examines the phenomenon of bone tunnel enlargement after hamstring tendon reconstruction, and the MRI findings of the asymptomatic knee after ACL reconstruction. Finally, comes an evaluation of the diagnostic value of MRI after patellar tendon ACL reconstruction.
REVIEW OF THE LITERATURE

Anterior cruciate ligament

Anatomy and function

The ACL, an intracapsular extrasynovial structure with a synovial envelope, is the main stabilizer of the knee for pivotal activities (Johnson 2004). Its proximal attachment is at the semicircular fossa on the posteromedial aspect of the lateral femoral condyle (Fig. 1). At the stronger distal attachment, the ligament fans out under the intercondylar roof and the transverse ligament to insert onto the tibial spines between the lateral and medial menisci (Ilaslan et al. 2005).

The ACL is a collection of fibrous fascicles rather than a cord. The fibers on the anterior border of the ACL are the longest, and those on the posterior edge the shortest. The ACL has a distinct crimped pattern that straightens as the ligament is put under strain. Although the ACL does not have bundles that are distinct from an anatomical perspective, it has been divided into two functional bundles, the anteromedial and the posterolateral bundle, which work synergistically to optimize its restraining function over the range of knee motion (Xerogeanes et al. 1995). The intra-articular length of the ACL is between 28 and 31 mm (Johnson 2004).

The ACL receives its blood supply from branches of the middle genicular artery, which forms a vascular synovial envelope around the ligament. These periligamentous vessels penetrate the ligament transversely and anastomose with a longitudinal network of endoligamentous vessels. The nerve supply to the ACL originates from the tibial nerve. Although the majority of fibers appear to have a vasomotor function, some fibers may serve a proprioceptive or sensory function (Arnoczky 1983).

Epidemiology of ACL tear

The ACL is the most frequently totally disrupted knee ligament (Johnson et al. 1992). Although in the general population this injury is relatively uncommon, it occurs frequently in athletes, particularly among females (Ireland et al. 2004). The prevalence of ACL injuries in the general population has been estimated at an annual incidence rate of one injury for every 3,500 people, resulting in approximately 95,000 new ACL tears per year in...
the United States (Daniel et al. 1994, Miyasaka et al. 1991). This estimate is probably low because more than 100,000 ACL reconstructions are performed annually in the United States (Owings et al. 1998). Although the incidence rate of ACL tears for female athletes ranges between 2.4 and 9.7 times as great as that of male athletes competing in similar activities, overall, more ACL reconstructions are performed on males in the United States because more males participate in high-risk sports, for example, American football (Owings et al. 1998).

In Finland, 2271 ACL reconstructions were performed in 2004. These comprised 68% male and 32% female patients, mean age 33 years (Niemi et al. 2005).

**Accompanying injuries**

Injuries to the ACL rarely occur in isolation. Coexisting injuries, including other ligament sprains, meniscal tears, articular cartilage injuries, and bone bruises, may affect the treatment and outcomes of ACL ruptures. It is very difficult to predict exactly how these will alter the results (Beynnon et al. 2005b).

ACL ruptures are often combined with meniscal tears and medial collateral ligament (MCL) ruptures (Arangio et al. 1998). Combined ACL and MCL ruptures can lead to more serious degenerative changes in the knee than an isolated rupture of the ACL or MCL injury (Kannus 1988, Lundberg et al. 1997).

However, a follow-up study of ACL reconstruction showed no large differences in 5- to 9-year results for patients with an isolated ACL tear and those with an ACL tear with accompanying injuries (Järvelä et al. 2001).

**ACL surgery**

**Indications**

A widely accepted indication for a reconstruction following an ACL tear is a high-risk lifestyle requiring heavy work, sports, or recreational activities (Daniel et al. 1994, Ferrari et al. 2001). Likewise, repeated episodes of giving way (pivot shift) despite rehabilitation are considered a strong indication for ACL reconstruction (Ferrari et al. 2001). Age, by itself, is not thought to be a significant factor, but younger patients tend to be more active (Sloane et al. 2002). ACL tears associated with severe injuries to other ligamentous structures in the joint, generalized ligamentous laxity, and recurrent instability with activities of daily living have all been factors in favor of surgical reconstruction (Ferrari et al. 2001).

An RCT by the Andersson group reported superior results in patients with primary suture of the ACL and augmentation with the iliotibial band, when compared to those with primary suture or conservative treatment (Andersson et al. 1991). Sandberg’s group, however, documented no difference between primary anterior cruciate suture versus non-operative treatment (Sandberg et al. 1987). No RCTs to date have been reported comparing patellar or hamstring tendon graft reconstruction with non-operative treatment in ACL-deficient patients.
Techniques

According to Eberhardt, early mention of the ACL appears in the ancient literature, and the first published scientific reports in the nineteenth century. The first surgical treatment of a ruptured ACL was carried out in 1895 by Robson’s performing a primary suture of the torn ligament. In 1903, Lange suggested a complete replacement of the injured ligament using silk ligaments, and in 1914, Grekow was probably the first who recommended autogenous transplants by using a fascia lata strip (Eberhardt et al. 2002). In 1917, Hey Groves presented his surgical technique that was the basis for ACL surgery in the following years (Hey Groves 1917). The modern phase of treatment began when both Jones and MacIntosh advocated reconstruction of the ACL with the patellar tendon (Jones 1970, MacIntosh 1976).

Surgical techniques that have been utilized for ACL surgery include primary suture of the ligament, ligament suture plus augmentation using various autogenous grafts, intra-articular transfer of the iliotibial band, and ligament reconstruction using autogenous grafts, allografts, or prosthetic devices (Engebretsen et al. 1989, Johnson et al. 1992, Paulos et al. 1992, Peterson et al. 2001).

In recent years, the central third of the patellar tendon and combined semitendinosus and gracilis (hamstring) tendons have become the most frequently used autograft types for ACL reconstruction. For the past two decades, the gold standard in ACL reconstruction has been the patellar tendon graft, but increasingly the hamstring tendon graft (Herrington et al. 2005).

Harvesting the patellar tendon graft, with bone plugs from the inferior pole of the patella and from the tibial tuberosity, has been the most commonly employed technique due to its inherent strength. This technique quite commonly has complications such as anterior knee pain and quadriceps weakness (Aglietti et al. 1993, Sachs et al. 1989). Metallic or bioabsorbable interference screws are used for patellar tendon graft fixation (Fu et al. 2000).

Intra-articular semitendinosus tendon reconstructions were described in the 1980s (Zaricznyj 1983). Today, the hamstring tendon graft is being employed with increasing frequency, since morbidity related to the donor site is minimal. Proposed disadvantages, however, include failure to achieve immediate rigid fixation to bone, and less stiffness than with a patellar tendon graft or the native ACL (Steiner et al. 1994). Metal plate (Rosenberg et al. 1997), cross-pin (Wolf 1998, 1999), and post fixation (Otero et al. 1993) techniques can be used in the femoral fixation of the hamstring tendon graft. Other fixation methods include metal or bioabsorbable interference screws, staples, and screw-washers (Corry et al. 1999, Vergis et al. 1995).

Allografts have been advocated as a viable option for ACL reconstruction. Decreased morbidity and decreased operative time have been attributed to the use of allografts, but the risk for infection, higher cost, and availability have been problems (Barber 2003). Prosthetic replacement of the ACL with synthetic material has not proven a satisfactory method for the ACL-deficient knee (Guidoin et al. 2000).
Complications

There exists a substantial group of patients with unsatisfactory results following ACL reconstruction (Vergis et al. 1995). The estimated graft failure rate after such ACL reconstruction has been reported as between 3% and 52% of cases, depending on the criteria used to define failure (Johnson et al. 1995, Noyes et al. 2001). Recurrent pathologic instability with graft failure, occurring in approximately 10% of patients, represents the most common reason for ACL reconstruction failure (Getelman et al. 1999). Causes of failed ACL reconstruction include improper surgical technique, biologic failure, trauma, and uncontrolled deficiency after secondary ligamentous trauma (Getelman et al. 1999, Noyes et al. 2001). Other documented complications after ACL reconstruction include graft impingement, bone tunnel enlargement, focal arthrofibrosis, cystic degeneration within the graft, and postoperative infection (Judd et al. 2006, Papakonstantinou et al. 2003, Wilson et al. 2004).

Donor site complications after patellar tendon ACL reconstruction include patellar fracture, patellar tendon rupture, and patellar pain (Sachs et al. 1989). In patients who have undergone ACL reconstruction, harvesting of the hamstring tendon does not, however, cause major donor site morbidity (Fu et al. 2000).

Postoperative evaluation

Clinical evaluation

Many clinical tests are available to detect ACL insufficiency. The most common are the Lachman test (Torg et al. 1976), and the pivot shift test (Galway et al. 1980). Instrumented measurements can also be useful in the determination of ACL instability (Bach et al. 1990, Daniel et al. 1985). The pivot shift examination has, however, been considered superior to instrumented measurements or Lachman examination in measuring ACL deficiency (Kocher et al. 2004).

Scoring systems have been introduced to evaluate treatment after disruption of the ACL. The International Knee Documentation Committee (IKDC) score involves the classification of subjective evaluation tools, symptoms, objective functional testing, and radiographic analysis. With this system, knees are given a grade of A to indicate normal, B to indicate almost normal, C for abnormal, or D for very abnormal (Hefti et al. 1993). The Lysholm knee score corresponds to the patients’ own opinion of knee function. A grade of 0 to 64 indicates a poor result; 65 to 83, an intermediate result; 84 to 90, a good result; and 91 to 100, a very good result (Lysholm et al. 1982). The Tegner activity level scale has grades from 0, which indicates infirmity, to 10, which indicates ability to participate in competitive sports (Tegner et al. 1985).

After ACL reconstruction, quadriceps and hamstring muscle strength can be measured to assess the dynamic status of the knee and to monitor
progress in rehabilitation (Harter et al. 1990, Kobayashi et al. 2004).

**Knee radiography**

Conventional radiography offers an easy and cost-effective means of routine evaluation after ACL reconstruction (Manaster et al. 1988). Radiographs, however, play a limited role in evaluation of the postoperative ACL, primarily demonstrating position of the bone tunnels, status of the orthopedic hardware, and bone plugs and progress of any post-traumatic osteoarthritis (Ilaslan et al. 2005). With the use of hamstring grafts and bioabsorbable implants, accurate assessment of the tunnel and implant position is difficult. The graft and its relation to anatomical landmarks cannot be evaluated directly (Agneskirchner et al. 2004).

**Magnetic resonance imaging**

Magnetic resonance imaging (MRI) has become an important tool in the evaluation of disorders of human joints and soft-tissue structures. Due to excellent soft-tissue contrast and multiplanar imaging capabilities, MRI offers the added benefit of direct visualization of the reconstructed ACL graft (Frick et al. 2006, White et al. 2005). As clinical examination of graft complications are often non-specific, and plain radiographs cannot directly visualize the graft and its adjacent soft tissues, MRI plays an important role in the diagnosis of complications (Papakonstantinou et al. 2003). MRI can serve to demonstrate graft placement and failure, impingement, and arthrofibrosis, as well as other causes of unsatisfactory outcome (McCauley 2005, White et al. 2005).

Proposed indications for MRI after ACL reconstruction include persistent knee instability, knee stiffness or pain, a new injury of the knee, infection, and preoperative evaluation for revision of a clinically apparent failed ACL graft (Recht et al. 2000).

Despite the presence of metallic fixation devices, a detailed evaluation of the knee can be obtained from standard imaging protocols. Conventional spin-echo (SE) and turbo spin-echo (TSE) techniques are commonly used to evaluate the knee postoperatively, but TSE techniques often produce fewer artifacts (Recht et al. 2000, Schatz et al. 1997). T2-weighted images are considered to be superior to T1-weighted images in detection of graft integrity (Frick et al. 2006). Fat-suppressed T2-weighted and STIR imaging eliminates high signal from fatty tissues (Papakonstantinou et al. 2003, Recht et al. 2000). To achieve high spatial resolution, a knee coil should be used to ensure an adequate signal-to-noise ratio (Papakonstantinou et al. 2003).

Imaging planes of the postoperative ACL include oblique sagittal images parallel to the plane of the graft and coronal images and axial images (Murakami et al. 1998, White et al. 2005).

**MRI features**

**Graft integrity**

An intact ACL graft has been described to appear on short echo time images with either low signal intensity (Howell et al. 1995, Rak et al. 1991) or intermediate signal intensity (Hong et al. 2005, Recht et
al. 2000). However, both intact and failed grafts can have intermediate signal intensities on short echo time images; therefore, T2-weighted MR images are considered to be crucial for detection of graft integrity (Iliaslan et al. 2005). Hong reported that T2-weighted images demonstrated a low signal intensity band in the intra-articular segment with only occasional longitudinal streaks of intermediate signal intensity (Hong et al. 2005). Some studies have reported that T2-weighted oblique axial images and oblique sagittal and coronal images proved useful in evaluating the integrity of the reconstructed ACL (Min et al. 2001, Roychowdhury et al. 1997).

MRI findings of a complete tear in the ACL graft include an absence of continuous, intact graft fibers. T2-weighted images reveal increased signal intensity, similar to that of fluid (Recht et al. 2000). A partial tear of the graft usually shows up as areas of increased T2-signal within the ACL graft, but with some intact fibers present (Iliaslan et al. 2005, Recht et al. 2000).

The appearance of the ACL graft varies with the type of graft used and with time after graft placement. With patellar tendon grafts, increased signal intensity may be apparent for 1 to 2 years after graft placement. After 2 years, the graft should appear as uniformly low signal intensity on all routinely used MRI sequences (McCauley 2005, Papakonstantinou et al. 2003).

Signal intensity of the hamstring tendon graft is almost identical to that of the patellar tendon graft. The hamstring tendon graft, however, is composed of four bundles distinguishable on MRI (White et al. 2005).

Periligamentous tissue

Between the first 1 to 3 months after ACL reconstruction, thick periligamentous synovial tissue envelopes the graft and provides its vascular supply (Arnoczky 1982, Johnson 1993). This amount of periligamentous tissue gradually decreases, becoming a thinner synovial fold surrounding the graft tissue after approximately 12 months. The process of gradual transformation of the patellar or hamstring tendon into tissue very similar to the native ACL is referred to as “ligamentization” (Amiel et al. 1986). Some authors have stated that the strength of the graft is decreased during the period of ligamentization, which results in its vulnerability to reinjury during this time period (White et al. 2005).

MRI can distinguish an ACL graft from periligamentous tissue (Howell et al. 1991b). The MRI appearance of periligamentous tissue in patellar and in hamstring tendon grafts is almost identical, but because the hamstring tendon graft is composed of four separate bundles, MRI often demonstrates periligamentous tissue between these separate bundles (White et al. 2005).

Contrast enhancement

The intravenously injected paramagnetic contrast agent diethylenetriamine dipentaacetic acid (DTPA) enhances vascularized tissues and in imaging provides additional information regarding the perfusion and vascularization of the ACL graft (Bach et al. 2002, Howell et al. 1995, Vogl et al. 2001).
Howell studied 45 knees during the first 2 years after ACL reconstruction with a hamstring graft; the graft itself remained avascular and showed no contrast enhancement. However, enhancing periligamentous tissue vascularized and covered the graft during the first month. He concluded that graft viability is more likely to depend on synovial diffusion than on intrinsic revascularization of the graft (Howell et al. 1995).

Vogl, performing 156 MRI examinations on 68 knees 2 to 104 weeks after patellar tendon ACL reconstruction, concluded that contrast-enhanced MRI allows accurate evaluation of morphology and function up to 3 months postoperatively and 1 to 2 years following ACL reconstruction surgery. In the 4- to 12-month postoperative period, contrast-enhancement offers no additional diagnostic information (Vogl et al. 2001).

Bach’s group, examining with MRI the degradation of bioabsorbable interference screws, observed enhancement of the tunnel contents after contrast material injection in 17 of 20 patients at 6 months, in 8 of 10 at 1 year, and in 7 of 8 at 2 years. Resorption of the screw did not appear to be related to clinical results (Bach et al. 2002).

**Bone tunnel placement**

Reconstruction of the ACL is a demanding operation. Arthroscopic visualization, combined with modern drill guides, allows surgeons to identify where they want to place the bone tunnels. Even with these advanced tools, however, placing the femoral and tibial bone tunnels in the desired locations is a challenging task (Beynnon et al. 2005a, Kohn et al. 1998).

Bone tunnel placement after ACL reconstruction has been typically measured by two-dimensional, radiographically based approaches. Numerous radiographic studies have reported that the most important technical consideration for achieving optimal results of ACL reconstruction is isometric positioning of bone tunnels in the femur and tibia (Almekinders et al. 1998, Howell et al. 2001, Markolf et al. 2002). It should be noted that the orientation of the ACL graft is different from that of the native ACL, due to the presence of a single bundle of fibers (White et al. 2005).

Femoral bone tunnel position is critical in obtaining isometry, which permits a constant length and tension of the graft through the range of motion of the knee (Recht et al. 2000). The femoral attachment should be placed just posterosuperior to the native ACL attachment. An anteriorly placed femoral tunnel will cause elongation of the graft and can lead to knee instability. An isometrically placed femoral tunnel should originate at the intersection of the posterior femoral cortex and intercondylar roof in the sagittal plane (Fig.2). In the coronal plane, the femoral tunnel should open superiorly above the lateral femoral condyle at the 11 o´clock position in the right knee and at 1 o´clock in the left knee. The tunnel should course inferiorly in an oblique fashion to exit at the superolateral aspect of the intercondylar notch (Fig.2) (Papakonstantinou et al. 2003).
In the sagittal plane, an isometrically placed tibial tunnel should open distally below the tibial tubercle and course posterosuperiorly to exit immediately anterior to the anterior tibial spine, and should be located at the intercondylar eminence in the coronal plane (Fig. 2) (Papakonstantinou et al. 2003). A classic study by Howell showed that an anterior tibial bone tunnel forces the graft to angulate around the distal edge of the intercondylar roof (Howell et al. 1992). Graft impingement most commonly occurs when the tibial bone tunnel is anterior to the Blumensaat line (Recht et al. 1996). To avoid roof impingement, the tibial tunnel should be centered 2 to 3 mm posterior to the center of the insertion of the native ACL on the tibia.

Bone tunnel evaluation using computer tomography (CT) shows that CT can be useful for precise evaluation of bone tunnel position and tunnel dimensions when detection is impossible from plain radiographs (Fink et al. 2001, Hoser et al. 2005, Webster et al. 2001).

Three-dimensional evaluation of bone tunnel placement can be performed by MRI. Agneskirchner et al. reported that T2-weighted sequences can be used for postoperative high-quality follow-up after ACL reconstruction and are an alternative to standard radiographs (Agneskirchner et al. 2004). MRI is a powerful tool for providing information regarding tunnel placement and adding valuable information on radiography report (Tomczak et al. 1997).

**Bone tunnel enlargement**

During the past decade, the phenomenon of bone tunnel enlargement has been observed as occurring after ACL reconstruction (Buelow et al. 2000, Fauno et al. 2005, Fink et al. 2001, Fules et al. 2003, Morgan et al. 2002, Wilson et al. 2004, Zijl et al. 2000). Its etiology is unknown but is most likely multifactorial (Wilson et al. 2004). Etiological factors described for bone tunnel enlargement can be divided into 2 categories: mechanical and biological. Mechanical factors include motion of the graft within the tunnel (Fink et al. 2001, Jagodzinski et al. 2005, Morgan et al. 2002), type of fixation (Fauno et al. 2005), use of hamstring autografts (Webster et al. 2001), improper graft placement (Zijl et al. 2000), and accelerated rehabilitation (Wilson et al. 2004). Graft swelling (Buelow et al. 2000), use of allograft tissue (Schulte et al. 1995), synovial fluid propagation within bony tunnels (Fink et al. 2001), and increased cytokine levels within the knee (Zysk et al. 2004) are all biological modes of inducing osteolysis and are eventually radiographic evidence of
tunnel enlargement. A recent study reported that female patients may have a greater risk for enlargement of the femoral bone tunnel than do males (Kobayashi et al. 2006).

Fauno’s group reported bone tunnel enlargement in patients with hamstring tendon graft and femoral endobutton fixation and bicortical screw and washer distal to the tibial tunnel. In 1-year follow-up radiographs, femoral and tibial bone tunnel enlargement of more than 2 mm was evident in 20 of 46 and in 16 of 46 patients, respectively (Fauno et al. 2005).

Zijl studied 26 patients with patellar tendon ACL reconstruction at a mean follow-up of 59 months (range, 41 to 84). The average tibial tunnel enlargement on the anteroposterior radiographs was 2.2 mm (SD, 2.5) and was 2.6 mm (SD, 2.4) on the lateral radiographs (Zijl et al. 2000).

MRI evaluation of tibial bone tunnel enlargement following hamstring tendon ACL reconstruction was performed by the Fules group. At a mean follow-up of 6.5 months, 24 patients underwent MRI assessment—with calculation of the cross-sectional area perpendicular to the long axis of the tibial tunnel—revealing a mean tibial tunnel enlargement of 33% (Fules et al. 2003).

**Graft impingement**

Graft roof impingement is a complication that can occur with an ACL graft when the graft abuts on the roof or wall of the intercondylar notch (Howell et al. 1991a). This complication is associated with anterior position of the tibial tunnel, with osteophytes at the margins of the intercondylar notch, or with a small intercondylar notch. Patients may present with pain or inability to fully extend the knee. Clinically observed impinging grafts may result in a higher incidence of knee instability than in unimpinged grafts (Howell et al. 1991b).

Less commonly, the ACL graft may impinge on the side walls of the intercondylar notch, as seen on coronal MR images. Causes of sidewall impingement include regrowth of cartilage at the site of notchplasty, an osteophyte, or a protruding screw (Trattnig et al. 1999). ACL grafts are also at potential risk of impingement against the PCL. When the Fujimoto group studied impingement against the PCL using 3-dimensional MRI, a vertically drilled femoral bone tunnel was associated with such impingement (Fujimoto et al. 2004).

One of the difficulties in studying impingement using MRI is that no uniform criteria exist in arthroscopy to provide the gold standard (McCauley 2005). Short echo time MRI may demonstrate increased signal intensity within the distal two-thirds of the graft at the site of impingement (Howell et al. 1991a).

**Artifacts**

MRI can be performed safely on patients with orthopedic metal implants because most implants have no ferromagnetic properties and have been fixed into bone (Shellock et al. 1993). Depending upon the implant utilized, a varying amount of artifact is observable on MRI at the location of the fixation material (White et al. 2005). However, fixation implants rarely affect interpretation because they are usually located outside the structures of interest (McCauley 2005).
Use of non-ferromagnetic metals such as titanium has reduced the amount of artifact in the postoperative knee (Suh et al. 1998). Following the use of bioabsorbable screws, a less severe imaging artifact is apparent. The additional benefit of bioabsorbable screws is that any associated artifacts tend to diminish over time (Bach et al. 2002, Warden et al. 1999).
AIMS OF THE STUDY

1. To prospectively compare the clinical outcome following ACL reconstruction using patellar and hamstring tendon graft techniques (Study I).

2. To prospectively compare the clinical outcome of hamstring tendon ACL reconstruction using femoral cross-pin or metal interference screw fixation techniques (Study II).

3. To analyze the phenomenon of bone tunnel enlargement following ACL reconstruction with the hamstring tendon graft (Study III).

4. To evaluate MRI appearance of the asymptomatic ACL reconstructed knee (Study IV).

5. To describe the diagnostic value of MRI after patellar tendon ACL reconstruction (Study V).

6. To describe the diagnostic value of contrast-enhanced MRI in evaluation of the ACL-reconstructed knee (Studies III-V).
MATERIALS AND METHODS

This research was performed at the ORTON Orthopaedic Hospital, Invalid Foundation, Helsinki (I-V) and at the Department of Radiology (III-V) of Helsinki University Central Hospital. The local ethics committee approved the study, and the patients had given their informed consent to participate.

Patients

Study I comprised 99 patients with a symptomatic deficiency following an ACL tear. All patients underwent ACL reconstruction and graft randomization into a patellar tendon group (n=51) or a hamstring tendon group (n=48) according to birth year (even year = patellar tendon, odd year = hamstring tendon). Exclusion criteria were previous ACL reconstruction and contralateral ACL injury. The patellar tendon group comprised 22 female and 29 male patients, mean age 30 years (range 15-53). The hamstring tendon group comprised 22 female and 26 male patients, mean age 32 years (range 13-56).

Five patients had additional grade 2 medial collateral ligament (MCL) tears in the operated knee and four had grade 3 MCL tears. Five of these patients were in the patellar tendon and four in the hamstring tendon group. Two of the patients with grade 3 tears were treated surgically at the time of the ACL reconstruction (one patient from each group). The rest received a knee brace to be worn preoperatively for 6 weeks if the reconstruction was not performed in the acute phase (n=2); otherwise, they received the brace just before or at the time of the operation. All of the MCL tears healed, and all knees were stable to valgus stress on clinical examination throughout the follow-up period.

For 26 patients, 28 meniscal repairs or resections were performed at the time of the ACL reconstruction. In the patellar tendon group were three partial resections and five repairs of the medial meniscus and six resections and two repairs of the lateral meniscus. In the hamstring tendon group were four resections and four repairs of the medial meniscus and three resections and one repair of the lateral meniscus.

In Study II, 62 patients with symptomatic deficiency following the ACL tear were randomized into groups with either cross-pin (n=31) or metal interference screw fixation (n=31) in ACL reconstruction with hamstring tendons. Randomization was done by sealed and numbered envelopes; the patients as well as physiotherapists were blinded to the method used. Exclusion criteria were previous ACL reconstruction, contralateral ACL injury, and concomitant grade 3 tears in other knee ligaments. There were three MCL tears (grade 2), all in the cross-pin-group, four meniscal resections and five refixations in the cross-pin group, and in the screw group five meniscal resections and two refixations. The cross-pin group comprised 12 female and 19 male patients with a median age of 27 years (range 15-56), and the screw group comprised 8 female and 23 male patients, median age 32 years (range 18-49).
Study III included 28 patients from the Study I randomization protocol (14 patellar tendon and 14 hamstring tendon group patients). In the hamstring tendon group, selection criterion was patient willingness to participate in MRI examination. Fourteen patients from the patellar tendon group were selected as controls for clinical evaluation (no MRI done). Each group contained 10 male and 4 female patients, median age 35 years.

Study IV included 20 patients (10 patellar tendon and 10 hamstring tendon group patients) from the Study I randomization protocol. The selection criterion was a clinically stable knee joint (negative Lachman test and negative pivot shift) at 2-year follow-up evaluated by two well-experienced orthopedic surgeons (J.S. and A.H.). The patellar tendon group comprised four female and six male patients, mean age 33 years (range 18-46), and the hamstring tendon group three female and seven male patients, mean age 37 years (range 31-45).

Study V had 25 patients with patellar tendon ACL reconstruction. In 13 patients with symptomatic knee instability, 14 knees were selected for a symptomatic knee group. Selection criteria were positive Lachman and pivot shift tests evaluated by the same two well-experienced orthopedic surgeons. In 12 patients, 14 asymptomatic knees were also selected for an asymptomatic knee group. Each patient for this group had a clinically successful ACL reconstruction with negative Lachman and pivot shift tests as evaluated by the two orthopedic surgeons. The symptomatic knee group comprised four female and nine male patients, mean age 34 years (range 20-55), and the asymptomatic group comprised five female and seven male patients, mean age 31 years (range 18-46).

**Surgical treatment**

Indication for ACL surgery was an ACL rupture confirmed by clinical diagnosis in an otherwise healthy patient who experienced instability in activities or wished to maintain his or her preinjury level of activity.

The two orthopedic surgeons performed all surgeries, and all four techniques were used equally by both surgeons. All patients were examined while under anesthesia (Lachman, drawer, and pivot shift tests), followed by routine diagnostic arthroscopy; also any necessary meniscal surgery was performed, followed by the ACL reconstruction in the same session.

In Study I, the time interval from injury to operation was 19 months (range, 1 week to 20 years) in the patellar tendon group, and 16 months (range, 2 weeks to 10 years) in the hamstring tendon group.

In Study II, the time interval from injury to operation was 6 months (range, 3 weeks to 13 years) in the cross-pin group, and 10 months (range, 4 weeks to 27 years) in the screw group.

**Patellar tendon technique**

The surgical procedure was an “outside-in” arthroscopically assisted 2-incision technique. The central one-third of the ipsilateral patellar tendon is resected in continuity with bone plugs from the distal patella and from the tibial tubercle (Clancy
et al. 1982). Specially designed “rear-entry” drill guides were used (Linvatec, Largo, Florida, USA). The fixation of the graft in the drill tunnels was performed with interference metal screws (Linvatec) (Fig.3). The drill bit was 9 mm or 10 mm, and the interference screw was either 8 or 9 mm.

Hamstring tendon technique

The hamstring tendons were harvested through a short vertical incision located medial to the tibial tuberosity with a graft harvester (Linvatec). The graft was constructed using the metal-plate, cross-pin, or screw- fixation method.

In the metal-plate group, the surgical procedure was the arthroscopic single-incision technique using double loop semitendinosus and gracilis tendons. The drill tunnels were 8 or 9 mm in diameter. Drill guides were used to confirm the correct position of the tunnels. To find the femoral entry point, we used the “bull’s eye” drill guide (Linvatec). Similarly to the Endobutton method, proximal graft fixation was achieved with use of a small metal plate (AO, Bern, Switzerland; Fig.4) (Barrett et al. 1995, Rosenberg et al. 1997). This plate was attached to the hamstring tendon graft with a Dacron (Davis & Geck, Danbury, Connecticut, USA) loop. Distal fixation was achieved by tying the graft ends around a cortical 4.5-mm screw secured with a spiked washer post (AO).

In the cross-pin group, double loop hamstring tendons were used to form the femoral fixation. Distally, all four tendons were secured with whip stitches of No.1 absorbable suture. The diameter of the graft was 8 to 10 mm. Drill guides were used, and the depth of the femoral tunnel was 40 mm. With TransFix (Arthrex, Naples, Florida, USA) instrumentation, a transverse drill tunnel was positioned through which a graft-passing wire (Arthrex) was introduced. With the help of the TransFix guide, the wire was pulled across the joint and out through the tibial drill tunnel. The graft loop was passed around the wire and pulled through the tibial drill tunnel to the blind end of the femoral tunnel. The cannulated TransFix implant, 40 or 50 mm in length, was introduced through the lateral femoral condyle,
guided by the metal wire, through the graft loop, and across the drill tunnel and advanced medially to the condyle. The graft was tightened manually to approximately a 40-N force with the knee in 30° of flexion. The knee was cycled several times through its range of motion. The distal ends of the graft were secured by an AO screw and AO spiked washer post (Fig.5).

In the screw group, graft diameter was 7 to 10 mm. Only semitendinosus tendon was used if there was sufficient volume (n=12); it was folded 3 times, with both ends securely sutured to form a tight bundle of tripled graft. The diameter of a single tendon was from 7 to 9 mm (the same as the 2-tendon grafts). In the remaining patients, the gracilis tendon was also harvested (n=19) with graft construction similar to the single tendons. The drill tunnels were made using guides (Linvatec), and the femoral tunnel with the “outside-in” technique using the rear-entry guide. The graft was tightened in the same way as in the cross-pin group. Round-headed interference screws (Linvatec), 7 mm (n=2), 8 mm (n=31), and 9 mm (n=29) in diameter and 20 mm in length, served to fix the graft (Fig.6).

**Figure 5.**
Anteroposterior radiograph 1 day after hamstring tendon ACL reconstruction demonstrating the femoral cross-pin fixation technique. Tibial fixation done with an AO screw and spiked washer post.

**Figure 6.**
Anteroposterior radiograph taken 1 day after hamstring tendon ACL reconstruction, demonstrating the femoral and tibial interference screw-fixation technique.

**Postoperative care**

The postoperative care and rehabilitation protocol was the same in all groups. No knee braces were used in the postoperative rehabilitation, except when MCL surgery was performed or when a patient with a partially torn MCL was treated with a brace. All knees were immediately mobilized. Full weight-bearing was allowed 2 weeks postoperatively. Active quadriceps muscle activity was delayed until 3 to 4 weeks postoperatively. Return to sports was allowed gradually, usually without limitations at 6 to 12 months postoperatively.
Follow-up and scoring

In Studies I and II, patients were examined preoperatively, and 1 and 2 years postoperatively.

In Study III, patients were examined preoperatively (n=28), 3 months (n=2), 1 year (n=2), and 2 years (n=24) postoperatively.

In Study IV, in addition to preoperative assessment, patients were examined in the patellar and hamstring tendon groups at a mean of 31.2 months (range 26-38) and at a mean of 27.6 months (range 23-35) postoperatively, respectively.

In Study V, patients were examined at a mean of 38.2 months (range 4-84) postoperatively in the symptomatic knee group, and at a mean of 29.7 months (range 16-70) postoperatively in the asymptomatic knee group.

Clinical evaluation

Lachman and pivot shift testing was performed by the two orthopedic surgeons. Objective anteroposterior (AP) knee laxity was determined with the CA 4000 arthrometer (OSI, Hayward, California, USA), and isokinetic muscle torque of the flexor-extensor system of the knee joint was measured with a dynamometer (Lido Multi-Joint II, West Sacramento, California, USA). Patients underwent routine clinical examination as well as completing the International Knee Documentation Committee (IKDC) evaluation forms. At 1 and 2 years postoperatively, patients completed the Lysholm knee score, Tegner activity level, and Kujala patellofemoral score forms.

In Study II, the Lachman test was graded as negative (-, hard endpoint, side-to-side difference <3 mm), slightly positive (+, side-to-side difference 3-5 mm), or clearly positive (+++, side-to-side difference >5 mm). Correspondingly, in the pivot shift test, the grading was negative (-), glide (+), or clearly positive (++).

Radiographic evaluation

Anteroposterior and lateral weight-bearing radiographs were obtained preoperatively and 2 years postoperatively. Postoperatively, we radiographically evaluated the location of the bone tunnels by dividing the Blumensaat line in the femur and proximal end of the tibia into 4 zones (I-IV) with zone I being the most anterior (Harner et al. 1994) (Fig.7).

In Studies II to III, bone tunnel width was measured from the AP radiographs at the widest possible site for the femur and tibia. Lateral measurements were made for tibial bone tunnels. Because of the oblique course of the drill tunnel, it was impossible reliably to measure the femoral bone tunnel widths on the lateral views.
In Study II, magnification of 0.9 was corrected on all bone tunnel measurements. In Study III, magnification was not corrected.

**MRI Evaluation**

MRI was performed with a 1.5-T imager (Vision, Siemens Medical systems, Erlangen, Germany) using a standard circular polarized knee coil supplied by the manufacturer. Oblique sagittal proton density-weighted (TR/TE, 2600/16) and T2-weighted (2600/98) TSE images and STIR images (TR/TE/TI, 5500/30/160) were obtained. The oblique sagittal images were placed along the longitudinal axis of the ACL by use of an axial scout view, with a 4-mm slice thickness with a 1.0-mm gap, one acquisition and a 196 x 256 matrix. In the oblique coronal view, 4-mm thick proton density- and T2-weighted (2200/16/98) TSE images with one acquisition, and T1-weighted (500/12) SE images with two acquisitions, were obtained along the plane of the ACL graft in the joint. The oblique coronal images were placed parallel to the longitudinal axis of the ACL graft in the joint by use of a sagittal scout view, with a 3-mm section thickness, no intersection gap, and a 240 x 256 matrix. In addition, axial T1-weighted SE images aligned perpendicular to the tibial bone tunnel were acquired in Study III. Subsequently, gadolinium-DTPA (Magnevist, Schering, Berlin, Germany) was infused intravenously at a dose of 0.1 mmol per kilogram of body weight. Finally, the oblique coronal and axial T1-weighted SE images were repeated for postcontrast evaluation. The field of view was 160 x 160 mm in all sequences. Imaging was complete 7 minutes after contrast medium administration, and the total imaging time for this protocol was 18 minutes.

The MR images were interpreted by a consensus of two readers (K.A.J and P.T.K), and the following findings were recorded:

1) Continuity and signal intensity of the ACL graft in oblique sagittal and oblique coronal proton density-, T1-, T2-weighted, and STIR images; signal intensity of the graft was graded as low when similar to the posterior cruciate ligament, intermediate when similar to the articular cartilage, and high when similar to subcutaneous fat.

2) Signal intensity and amount of periligamentous tissue between and around the ligamentous graft on oblique sagittal and oblique coronal proton density-, T1-, T2-weighted, and STIR images.

3) Enhancement of the graft itself and of periligamentous tissues. The grading was none, moderate, or marked enhancement.

4) Amount of fluid in the knee joint on oblique sagittal STIR images, with grading normal, minor, or marked effusion.

5) Position of the femoral and tibial bone tunnels on oblique sagittal MR images, with grading into four zones (I-IV). The optimal femoral position was defined as zone IV in the lateral parasagittal image (Fig.8, left). The optimal tibial position was defined as zone II in the mid-sagittal image (Fig.8, right).
Figure 8. Schematic illustration of lateral para-sagittal (left) and mid-sagittal (right) MR images demonstrating optimal position of the femoral and tibial bone tunnels, defined as zones IV and II.

6) Artifacts from the metallic fixation devices.

7) Additional findings: cysts, bone marrow edema, localized anterior arthrofibrosis (cyclops lesion), and meniscus status.

8) Anteroposterior and sagittal diameters (mm) of the bone tunnels measured from oblique sagittal and oblique coronal images in Study III. These measurement points in femur and tibia were the same in radiography and in MRI.

Arthroscopic evaluation

In Study V, all 14 symptomatic knees underwent arthroscopy at a mean of 10 days (range 1-45) after MRI. If indicated, additional procedures performed were revision ACL and meniscus surgery. The surgeon was not blinded to the MRI report before arthroscopy.

Statistical methods

In Studies I to IV, statistical analysis was performed by the BMDP statistical package (Statistical Solutions Ltd., Cork, Ireland). The SPSS 13.0 for Windows software (SPSS Inc., Chicago, Illinois, USA) was used in Study V. The minimum level of significance was $P = 0.05$.

In Study I, when appropriate, the chi-square test, Student’s $t$-test, analysis of variance, and regression analysis were employed in comparing the groups.

In Study II, the parametric data between the groups were evaluated by Student’s $t$-test. The non-parametric data were evaluated with the chi-square (between the groups) and with McNemar’s or Sign tests (comparison over time within a group).

In Study III, a paired $t$-test was used to assess the statistical difference between immediate postoperative and follow-up radiographs in the hamstring tendon group. The linear correlation (Pearson) between the dimensions of the bone tunnels detected on radiographs and on MRI was calculated by regression analysis. The chi-square test and analysis of variance were used in assessment between the groups.

In Study IV, the Mann-Whitney U-test was used in comparing clinical findings between the groups.

In Study V, the Mann-Whitney U-test served to compare the clinical findings between the groups. MRI findings between the groups were compared by use of the linear-by-linear trend test. Specificity and
sensitivity of graft integrity findings and bone tunnel placement for diagnosing ACL instability were calculated separately, and by combining these findings with CIA 2.1.2 software (British Medical Journal Publishing Group, London, UK).
RESULTS

Preoperative evaluation

In Studies I to III, no statistically significant differences appeared between the groups with respect to gender, age, time from injury to operation, preoperative knee stability tests, knee scores, or IKDC-classification (Tables 1-3). In Study I, the mean Lysholm knee score was, however, slightly higher in the patellar tendon group (Table 1).

TABLE 1. PREOPERATIVE EVALUATION IN STUDY I.

<table>
<thead>
<tr>
<th></th>
<th>Patellar tendon (n=51)</th>
<th>Hamstring tendon (n=48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP knee stability, side-to-side difference (mm)</td>
<td>5.5 (-3.3-12.8)</td>
<td>5.9 (-2.3-15.4)</td>
</tr>
<tr>
<td>Overall IKDC score (A/B/C/D)</td>
<td>0/2/18/16</td>
<td>0/0/18/22</td>
</tr>
<tr>
<td>Lysholm knee score (0-100)</td>
<td>74 (46-94)</td>
<td>68 (28-90)</td>
</tr>
<tr>
<td>Tegner activity level (0-10)</td>
<td>2.9 (0-6)</td>
<td>3.1 (2-10)</td>
</tr>
<tr>
<td>Kujala patellofemoral score (0-100)</td>
<td>81 (55-100)</td>
<td>75 (28-100)</td>
</tr>
</tbody>
</table>
* P=0.044

TABLE 2. PREOPERATIVE EVALUATION IN STUDY II.

<table>
<thead>
<tr>
<th></th>
<th>Cross-pin (n=31)</th>
<th>Screw (n=31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP knee stability, side-to-side difference (mm ± SD)</td>
<td>6.3 ± 3.9</td>
<td>7.7 ± 4.2</td>
</tr>
<tr>
<td>Overall IKDC score (A/B/C/D)</td>
<td>0/2/17/10</td>
<td>0/1/11/17</td>
</tr>
<tr>
<td>Lysholm knee score (median, 0-100)</td>
<td>70 (24-100)</td>
<td>74 (30-95)</td>
</tr>
<tr>
<td>Tegner activity level (median, 0-10)</td>
<td>3 (0-6)</td>
<td>3 (0-6)</td>
</tr>
<tr>
<td>Kujala patellofemoral score (median, 0-100)</td>
<td>78 (45-100)</td>
<td>81 (27-98)</td>
</tr>
</tbody>
</table>

TABLE 3. PREOPERATIVE EVALUATION IN STUDY III.

<table>
<thead>
<tr>
<th></th>
<th>Patellar tendon (n=14)</th>
<th>Hamstring tendon (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP knee stability, side-to-side difference (mm ± SD)</td>
<td>7.6 ± 3.4</td>
<td>6.5 ± 3.2</td>
</tr>
<tr>
<td>Lysholm knee score (0-100)</td>
<td>68</td>
<td>71</td>
</tr>
<tr>
<td>Tegner activity level (median, 0-10)</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Postoperative evaluation

Of the 99 initial patients in Study I, 89 were available for the 2-year follow-up. Of the ten patients not available, eight (all from the patellar tendon group) were unable to attend the follow-up examination, and follow-up data for the remaining two patients (both in the hamstring tendon group) were excluded because they had each ruptured their grafts in high-energy trauma and had undergone reoperations during the 2-year follow-up period. Thus, 10% of patients were lost or excluded from the follow-up. In the patellar tendon group, 43 and in the hamstring tendon group, 46 patients were evaluated at a minimum of 21 months (range 21-38) after surgery.

In Study II, 1-year follow-up was possible in 26 patients in the cross-pin group and 30 in the screw group (90%). However, the six missing patients at one year were again available for the 2-year follow-up. For the 2-year follow-up, 26 of the cross-pin group and 30 in the screw group were available (90%); a total of six were thus missing, but these patients were different ones from those participating in the 1-year follow-up.

Stability and knee scores

Study I showed no significant differences between the groups with respect to knee laxity tests, Lysholm knee score, Tegner activity level, or Kujala patellofemoral score in the 2-year follow-up (Tables 4 and 5). However, the Lysholm knee score increased from preoperatively to the 2-year follow-up significantly more in the hamstring tendon group than in the patellar tendon group (23 and 15, P=0.022). There was a positive pivot shift test at the 2-year follow-up in three patients in the patellar tendon group and in three in the hamstring tendon group (Table 4). Mean time from injury to operation was 6 years for the six patients with a positive pivot shift test 2 years postoperatively, whereas those patients with a negative pivot shift underwent surgery at a mean of one year after injury. The 2-year postoperative mean Tegner activity level was 6.1 (range, 2 to 9) in the patellar tendon group and 6.0 (range, 0 to 10) in the hamstring tendon group.

Study II showed no differences between the groups in the 1- or 2-year follow-up examinations with respect to knee laxity tests, Tegner activity level, Lysholm knee score, or Kujala patellofemoral score (Tables 6-9). The mean preoperative AP side-to-side difference was 6.3 mm in the cross-pin and 7.7 mm in the screw group (Table 2), diminishing to 2.2 mm in the cross-pin and 1.8 mm in the screw group by the 2-year follow-up. (Table 7).

Studies III to IV: No statistically significant differences existed between the groups with respect to knee laxity tests, Lysholm knee score, or Tegner activity level (Tables 10 and 11).

Study V: The mean AP side-to-side difference was significantly higher in the symptomatic group (4.1 mm vs. 0.25 mm, P=0.037, Table 12). Additional statistical analysis excluding the six knees with bilateral ACL reconstruction revealed a significant difference between groups with respect to AP knee laxity,
Lysholm knee score, Tegner activity level, or Kujala patellofemoral score findings (P<0.05).

**Table 4. Clinical and instrumented testing 2 years postoperative in Study I.**

<table>
<thead>
<tr>
<th>Test</th>
<th>Patellar tendon</th>
<th>Hamstring tendon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pivot shift-test (positive/negative)</td>
<td>3/40</td>
<td>3/43</td>
</tr>
<tr>
<td>Lachman test (positive/negative)</td>
<td>8/35</td>
<td>8/38</td>
</tr>
<tr>
<td>AP knee stability, side-to-side difference (mm)</td>
<td>1.7 (-3.7-7.8)</td>
<td>1.2 (-4.3-7.4)</td>
</tr>
</tbody>
</table>

**Table 5. Lysholm knee scores 2 years postoperative in Study I.**

<table>
<thead>
<tr>
<th>Score (points)</th>
<th>Patellar tendon %</th>
<th>Hamstring tendon %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent (95-100)</td>
<td>22</td>
<td>51</td>
</tr>
<tr>
<td>Good (84-94)</td>
<td>14</td>
<td>33</td>
</tr>
<tr>
<td>Fair (65-83)</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Poor (&lt;65)</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 6. Knee stability evaluation 1- and 2 years postoperative in Study II.**

<table>
<thead>
<tr>
<th>Test</th>
<th>-</th>
<th>+</th>
<th>++</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lachman</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 year postoperative</td>
<td>19</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>cross-pin</td>
<td>19</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>screw</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 year postoperative</td>
<td>21</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>cross-pin</td>
<td>22</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>screw</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pivot shift</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 year postoperative</td>
<td>22</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>cross-pin</td>
<td>25</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>screw</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2 year postoperative</td>
<td>23</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>cross-pin</td>
<td>24</td>
<td>5</td>
<td>1</td>
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<tr>
<td>screw</td>
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**Table 7. Anterior-posterior laxity (side-to-side difference) 1 and 2 years postoperative in Study II.**

<table>
<thead>
<tr>
<th>Test</th>
<th>Cross-pin</th>
<th>Screw</th>
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</thead>
<tbody>
<tr>
<td>1 year postoperative (mm)</td>
<td>3.1 ± 3.4</td>
<td>3.1 ± 3.9</td>
</tr>
<tr>
<td>2 year postoperative (mm)</td>
<td>2.2 ± 3.6</td>
<td>1.8 ± 2.8</td>
</tr>
</tbody>
</table>
### Table 8. Anterior-posterior laxity in Study II. Data stratified to <3 mm, 3-5 mm, and >5 mm side-to-side difference.

<table>
<thead>
<tr>
<th></th>
<th>Screw preop</th>
<th>Screw 1 year</th>
<th>Screw 2 year</th>
<th>Cross-pin preop</th>
<th>Cross-pin 1 year</th>
<th>Cross-pin 2 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3 mm</td>
<td>3</td>
<td>13</td>
<td>18</td>
<td>3</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>3-5 mm</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>&gt;5 mm</td>
<td>22</td>
<td>9</td>
<td>5</td>
<td>20</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 9. Tegner-activity level, Lysholm knee score, and Kujala patellofemoral score 1 and 2 years operatively in Study II

<table>
<thead>
<tr>
<th></th>
<th>Cross-pin group</th>
<th>Screw group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 year postoperative</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tegner (0-10)</td>
<td>6 (4-9)</td>
<td>6 (2-9)</td>
</tr>
<tr>
<td>Lysholm (0-100)</td>
<td>90 (69-100)</td>
<td>95 (52-100)</td>
</tr>
<tr>
<td>Kujala (0-100)</td>
<td>95 (75-100)</td>
<td>98 (61-100)</td>
</tr>
<tr>
<td><strong>2 years postoperative</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tegner (0-10)</td>
<td>6 (2-10)</td>
<td>6 (2-10)</td>
</tr>
<tr>
<td>Lysholm (0-100)</td>
<td>94 (65-100)</td>
<td>95 (65-100)</td>
</tr>
<tr>
<td>Kujala (0-100)</td>
<td>96 (63-100)</td>
<td>97 (57-100)</td>
</tr>
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</table>

### Table 10. Clinical follow-up findings in Study III

<table>
<thead>
<tr>
<th></th>
<th>Patellar group</th>
<th>Hamstring group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 year postoperative</strong></td>
<td>n=13</td>
<td>n=13</td>
</tr>
<tr>
<td>AP laxity, side-to-side difference (mm)</td>
<td>2.1 ± 2.2</td>
<td>2.1 ± 2.2</td>
</tr>
<tr>
<td>Lysholm knee score</td>
<td>92 ± 8</td>
<td>88 ± 15</td>
</tr>
<tr>
<td>Tegner activity level (median)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>2 years postoperative</strong></td>
<td>n=12</td>
<td>n=10</td>
</tr>
<tr>
<td>AP laxity, side-to-side difference (mm)</td>
<td>1.3 ± 2.1</td>
<td>0.8 ± 1.5</td>
</tr>
<tr>
<td>Lysholm knee score</td>
<td>89 ± 21</td>
<td>92 ± 15</td>
</tr>
<tr>
<td>Tegner activity level (median)</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 11. Clinical 2-year follow-up findings in Study IV.

<table>
<thead>
<tr>
<th></th>
<th>Patellar group</th>
<th>Hamstring group</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP knee laxity, side-to-side difference (mm)</td>
<td>-0.38 ± 2.1</td>
<td>0.82 ± 1.5</td>
</tr>
<tr>
<td>Lysholm knee score, (0-100)</td>
<td>95.7 ± 6.3</td>
<td>92.4 ± 15.5</td>
</tr>
<tr>
<td>Tegner activity level, (0-10)</td>
<td>6.3 ± 1.4</td>
<td>5.8 ± 1.7</td>
</tr>
</tbody>
</table>
Study I revealed no significant differences between the groups with respect to IKDC classification at the 2-year follow-up (Table 13).

Study II showed no differences between the groups in the preoperative IKDC classification, with 27 of the cross-pin and 28 of the screw group patients being classified as IKDC C or D (Table 14). For the most acute cases, the preoperative IKDC classification was not used. No differences existed between the groups at the 1- or 2-year follow-up. At the 2-year follow-up, 22 of 26 (85%) of the cross-pin group patients and 22 of 30 (73%) in the screw group fell in the IKDC A or B categories.

In Study I, a marginal difference appeared between groups in the range of motion at the 2-year follow-up examination. The mean extension was 0.5° in the patellar tendon and -0.2° in the hamstring tendon group (P=0.048), with no difference in flexion: a mean 140° of flexion in both groups.

In Study II, no difference appeared between the groups with respect to range of motion at the 1- or 2-year follow-up. One year postoperatively, five patients (three in the cross-pin and two in the screw group) showed 3° to 6° of extension deficit. The range of motion was 147° and 145° in the cross-pin and in the screw groups, respectively. By the 2-year follow-up, the range of motion had improved to 152° in the cross-pin group and 156° in the screw group. Only one patient (in the cross-pin group) had an extension deficit (10°).

### TABLE 12. CLINICAL FOLLOW-UP FINDINGS IN STUDY V.

<table>
<thead>
<tr>
<th></th>
<th>Symptomatic knees</th>
<th>Asymptomatic knees</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AP knee laxity, side-to-side difference (mm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.1±4.7</td>
<td>0.25±2.6</td>
<td>0.037</td>
</tr>
<tr>
<td>Kujala patellofemoral score, (0-100)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>74±15</td>
<td>96±5.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lysholm knee score, (0-100)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>68±16.1</td>
<td>96±5.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Tegner activity level, (0-10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.3±2.5</td>
<td>5.8±1.3</td>
<td>0.009</td>
</tr>
</tbody>
</table>

**IKDC classification**

**Range of motion**
TABLE 13. IKDC CLASSIFICATION 2 YEARS POSTOPERATIVE IN STUDY I.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Patellar tendon</th>
<th>Hamstring tendon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=43</td>
<td>%</td>
</tr>
<tr>
<td>A (normal)</td>
<td>14</td>
<td>32</td>
</tr>
<tr>
<td>B (nearly normal)</td>
<td>20</td>
<td>47</td>
</tr>
<tr>
<td>C (abnormal)</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td>D (severely abnormal)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

TABLE 14. IKDC CLASSIFICATION PREOPERATIVELY AND 1 AND 2 YEARS POSTOPERATIVELY IN STUDY II.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
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<tr>
<td>Preoperative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cross-pin</td>
<td>0</td>
<td>2</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>screw</td>
<td>0</td>
<td>1</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>1-year postop.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cross-pin</td>
<td>6</td>
<td>19</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>screw</td>
<td>11</td>
<td>14</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>2-years postop.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cross-pin</td>
<td>7</td>
<td>15</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>screw</td>
<td>9</td>
<td>13</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

Muscle strength

In Study I, the 1-year follow-up isokinetic quadriceps muscle torque (percentage of the contralateral knee) at 60 deg/sec was significantly higher in the hamstring tendon group than in the patellar tendon group (85% versus 79%, P=0.045). At the 2-year follow-up, no significant differences existed between the groups with respect to isokinetic muscle performance.

A significant positive correlation (P<0.05) appeared between isokinetic extension and flexion torques (60 deg/sec and 180 deg/sec) and Lysholm knee scores at one year postoperatively, but this correlation had disappeared by the 2-year follow-up. There existed, however, no correlation between isokinetic torque and laxity measurements, placement of the graft as seen on radiographs, or grade of arthrosis.

Study II showed no differences between the groups in terms of the isokinetic muscle performance at the 1- or 2-year follow-up.

Complications

In Study I, one postoperative infection occurred one week after the ACL reconstruction in the patellar tendon group. The bacterial culture was negative, but the clinical presentation indicated a purulent arthritis. After arthroscopic debridement and profuse lavage, the patient recovered uneventfully. The knee remained stable, and showed no arthritic changes at 2 years postoperatively, nor did any deep vein thromboses occur in either group. Nearly all patients
experienced numbness lateral to the tibial incision scar, but without any signs of a neuroma complication.

Two revision ACL reconstructions in the hamstring tendon group had to be performed after a new injury had torn the reconstructed ligament. In that group, the tibial AO fixation post was removed by 2 years postoperatively in 32 cases in patients who had discomfort at the fixation site.

Study II revealed no postoperative infections. Two patients reported annoying numbness around the harvest incision scar, and one patient had a large area of sensibility defect anteromedially in the leg. In one case, a deep vein thrombosis was suspected (cross-pin group).

Additional procedures after the ACL reconstruction were performed during the follow-up in 25 cases (23 in the cross-pin and 2 in the screw group). The tibial fixation post of the cross-pin reconstructions (AO screw and washer) was removed in 15 patients 6 to 24 months postoperatively. Three medial meniscus resections were necessary, two in the cross-pin and one in the screw group. In one patient in the cross-pin group, a cyclops lesion was removed. One TransFix cross-pin had to be repositioned because of lateral migration, and another had to be extracted. A new injury occurred in one case in the screw group; at arthroscopy, the reconstructed ligament was uninjured, but there was synovitis and scar tissue, as also in another patient in the cross-pin group without a reinjury. One patient had slight valgus instability in the cross-pin group after an old MCL tear, and this was treated with reconstruction of the ligament using contralateral hamstring tendons 15 months after the ACL reconstruction.

One revision ACL reconstruction had to be performed after a new injury had torn the reconstructed ligament (cross-pin group), and a revision was scheduled in another case that became unstable without reinjury (screw group).

**Radiographic evaluation**

**Bone tunnel placement**

In Study I, the postoperative radiographs (n=96; radiographs from three patients missing) showed that the bone tunnels were placed in the anterior part of tibia more often in the patellar tendon group than in the hamstring tendon group. In the patellar tendon group, 14 of 50 tibial tunnels were in zone I, whereas in the hamstring tendon group 3 of 46 were located in zone I (P=0.0059). No differences existed in clinical outcome with respect to the placement of these bone tunnels.

In Study II, femoral bone tunnel positions on postoperative radiographs were 2 in zone III and 24 in zone IV for the cross-pin group; the corresponding locations for the screw group were one and 27 (NS). Tibial locations for the cross-pin group were one in zone I and 25 in zone II. The corresponding positions for the screw group were 0 and 25 (NS).

**Bone tunnel enlargement**

On radiographs taken immediately postoperatively in the hamstring tendon group in Study III, the margins of the bone tunnels in femur and tibia were difficult to identify,
but the margins were sclerotic and easily detected one and 2 years postoperatively. All patients with 1-year and 2-year follow-ups in the hamstring tendon group showed bone tunnel enlargement. On AP radiographs, the diameter of the bone tunnels increased during 2 years of follow-up from 8.9 mm to 11.7 mm for tibia (23%, \( P=0.003 \)) and from 8.9 mm to 13.2 mm for femur (33%, \( P=0.01 \)) (Table 15, Figs.9a-b). Lateral view radiographs showed no significant difference regarding the tibial tunnel.

Bone tunnel dimensions measured on radiography and on MRI 2 years postoperative on tibial AP and lateral views showed a significant correlation: \( r=0.58, \ P=0.05 \); and \( r=0.77, \ P=0.004 \), respectively (Table 15). The correlation was poor (\( r=0.37, \ P=0.39 \)) on femoral lateral views.

Study II had 25 radiographs from both groups available for the 2-year postoperative evaluation. The original bone tunnels were 7 to 10 mm. At the 2-year follow-up, these had increased to a mean of 12 and 11 mm (magnification not corrected) in the cross-pin and screw groups, respectively (NS), with a range of 9 to 20 mm in the AP femoral measurement (Table 16).

### Table 15. Bone tunnel dimensions on radiography and on MRI in the hamstring tendon group (magnification of 0.9 corrected on radiography).

<table>
<thead>
<tr>
<th>Bone Tunnel Type</th>
<th>Postoperative radiography (mm)</th>
<th>2 years postop. radiography (mm)</th>
<th>2 years postop. MRI (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibial bone tunnel (AP)</td>
<td>8.9 ± 1.0</td>
<td>11.7 ± 1.0</td>
<td>11.4 ± 1.5</td>
</tr>
<tr>
<td>Tibial bone tunnel (lateral)</td>
<td>8.4 ± 0.4</td>
<td>11.9 ± 1.3</td>
<td>11.7 ± 1.6</td>
</tr>
<tr>
<td>Femoral bone tunnel (AP)</td>
<td>8.9 ± 1.4</td>
<td>13.2 ± 1.8</td>
<td>not available</td>
</tr>
<tr>
<td>Femoral bone tunnel (lateral)</td>
<td>not available</td>
<td>11.9 ± 0.8</td>
<td>12.1 ± 0.8</td>
</tr>
</tbody>
</table>

### Table 16. Bone tunnel dimensions on radiography 2-years postoperatively in the cross-pin and screw groups (M magnification not corrected).

<table>
<thead>
<tr>
<th>Bone Tunnel Type</th>
<th>Cross-pin (mm)</th>
<th>Screw (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral bone tunnel (AP)</td>
<td>12.2±2.4</td>
<td>11.1±1.7</td>
</tr>
<tr>
<td>Tibial bone tunnel (AP)</td>
<td>11.6±1.5</td>
<td>11.4±1.6</td>
</tr>
<tr>
<td>Tibial bone tunnel (lateral)</td>
<td>11.2±1.7</td>
<td>10.9±1.5</td>
</tr>
</tbody>
</table>
Figure 9.
A 40-year-old male patient with hamstring tendon-metal plate ACL reconstruction.

A. Two days postoperative AP and lateral knee radiographs. A 9-mm drill bit was used in the hamstring tendon ACL reconstruction.

B. Two-year postoperative radiographs demonstrating sclerotic margins and marked femoral and tibial bone tunnel enlargement.

C. Two-year postoperative oblique sagittal proton density weighted (left) and oblique coronal T1-weighted (right) MR images. The graft shows low, homogeneous signal intensity (arrows). Intermediate signal intensity streaks of periligamentous tissue are apparent between and around the ligamentous graft. The knee was asymptomatic at the 2-year follow-up.
**MRI evaluation**

**Graft integrity**

In all asymptomatic knees, the ligamentous graft itself was continuous and showed homogeneous, low signal intensity on all T2-weighted and STIR images (Figs. 10a, 12a, 12c).

On proton density- and T1-weighted images, the intra-articular segment of the graft showed an inhomogeneous localized area of intermediate or high signal intensity where no continuous graft was apparent in 10 knees in Study IV: 3 (30%) in the patellar tendon group, in 7 knees (70%) in the hamstring tendon group (Fig. 10b); and in 19 knees in Study V: 13 (93%) in the symptomatic group, and in 6 knees (43%) in the asymptomatic group (Fig. 11b).

In Study V, the ACL graft was continuous and showed homogeneous and low signal intensity on T2-weighted images in 6 (43%) symptomatic knees (Fig. 11a) and in 14 (100%) asymptomatic knees (Fig. 12a). In eight (57%) asymptomatic knees, the graft showed low signal intensity on all oblique sagittal images (Fig. 12).

Sensitivity and specificity for diagnosing ACL instability on MRI for graft continuity was 55% (95% confidence interval, CI, 31-76%) and 94% (95% CI, 77-99%); and for graft signal intensity, 50% (95% CI, 29-72%) and 94% (95% CI, 76-99%).

---

**Figure 10.** A 34-year-old male from the hamstring tendon group 25 months after surgery with an asymptomatic knee.

A. **On an oblique sagittal T2-weighted (2600/98) TSE image,** the graft shows homogeneous, low signal intensity in the intra-articular segment (arrowhead). A cyst is visible adjacent to the posterior tibial bone tunnel (arrow).

B. **On an oblique sagittal proton density weighted (2600/16) TSE image,** the intra-articular segment of the graft shows a localized area of intermediate signal intensity (arrowheads). This signal intensity is similar to that of articular hyaline cartilage (asterix).

C. **On an oblique sagittal STIR (5500/30/150) image,** high signal intensity indicating bone marrow edema is visible posterolateral to the tibial bone tunnel (arrowhead).
Figure 11. A 28-year-old male patient 36 months after patellar tendon ACL reconstruction with symptomatic knee instability. Arthroscopy revealed an intact but lax graft. Revision ACL surgery was indicated.

A. On an oblique sagittal T2-weighted (2600/98) TSE image, a wide continuous graft with a homogenous low signal intensity graft is visible in the intra-articular segment (arrow).

B. On an oblique sagittal proton density weighted (2600/16) TSE image, an intra-articular segment of graft shows an incontinuous localized area of intermediate signal intensity (arrow). The femoral bone tunnel is placed too far anterior (zone II), as seen exceptionally well on this mid-sagittal image (asterisk). Typically, the femoral bone tunnel is best visualized on lateral para-sagittal images.

Figure 12. A 32-year-old male patient 72 months after patellar tendon ACL reconstruction with an asymptomatic knee. In the joint space, the ACL graft is visible continuous with homogenous low signal intensity on oblique sagittal T2-weighted (2600/98) (a) and proton density weighted (2600/16) (b) TSE images, and on an oblique sagittal STIR (5500/30/150) image (c) (arrows). The tibial bone tunnel is located in the optimal position (zone II, asterisk).
Periligamentous tissue

In all knees, intermediate signal intensity streaks of periligamentous tissue were detectable between and around the graft fibers on proton density- and T1-weighted images. This periligamentous tissue was present in varying amounts in the joint and in the proximal tibial bone tunnel (Figs. 13a, 14b), and it was best detected on oblique coronal T1-weighted images (Fig. 13c). On oblique sagittal T2-weighted and STIR images, periligamentous tissue was typically visible as intermediate signal intensity streaks along and within the graft (Fig. 13b). However, detectable periligamentous tissue was less visible on these sequences than on proton density- and T1-weighted images. The appearance of periligamentous tissue was similar in both patellar and hamstring tendon groups.

Figure 13. A 35-year-old male from the hamstring tendon group 25 months after surgery.

A. On an oblique sagittal proton density weighted (2600/16) TSE image, longitudinal streaks of periligamentous tissue (arrowhead) are visible between the individual graft fibers.

B. On an oblique sagittal STIR (5500/30/150) image, the longitudinal streaks demonstrate intermediate signal intensity (arrowhead).

C. The periligamentous tissue (arrowheads) is most evident on an oblique coronal T1-weighted (500/12) SE image with intermediate signal intensity similar to articular hyaline cartilage (asterisk).
Figure 14. A 26-year-old male patient imaged 32 months after patellar tendon ACL reconstruction with symptomatic knee instability. Regardless of intact graft and optimal bone tunnel placement, arthroscopy revealed a lax graft; revision ACL surgery was therefore indicated.

A. On an oblique sagittal T2-weighted (2600/98) TSE image, an intact graft with homogeneous low signal intensity is apparent (arrow).

B. On a sagittal proton density-weighted (2600/16) TSE image, longitudinal intermediate signal intensity streaks are visible around the graft in the joint space (arrows).

Contrast enhancement

In all knees, the graft itself did not enhance on postcontrast T1-weighted images (Figs.15-17).

In Study III, the periligamentous tissue showed moderate contrast enhancement in 11 knees (79%). In one patient, a 3-month postoperative MRI scan showed abundant periligamentous tissue with marked contrast enhancement (Fig.16).

In Study IV, the periligamentous tissues in the joint and in the proximal tibial bone tunnel showed contrast enhancement in 10 (50%) and 12 cases (60%), respectively (Table 17; Fig.17). In five cases (four in the patellar tendon group and one in the hamstring tendon group) no contrast enhancement appeared in either the intra-articular or the tibial periligamentous tissues.

In Study V, of the 11 knees in each group, periligamentous tissues in the joint and in the tibial bone tunnel showed moderate contrast enhancement in 6 (55%) symptomatic and 3 (27%) asymptomatic knees (NS, P=0.083).
Figure 15. Two years postoperative axial pre- (left) and postcontrast (right) T1-weighted (500/12) SE image from the hamstring tendon group. The ligamentous graft shows low, homogeneous signal intensity with intermediate signal intensity tissue between and around the graft fibers. On the postcontrast image, the graft itself shows no increase in signal intensity, and the periligamentous tissue shows moderate contrast enhancement.

Figure 16. Three months postoperative axial T1-weighted (500/12) SE pre- (left) and postcontrast (right) images from the hamstring tendon group demonstrating abundant periligamentous tissue. On the postcontrast image, the periligamentous tissue shows marked contrast enhancement between and around the ligamentous graft fibers.

Figure 17. A 42-year-old female patient in the hamstring tendon group 23 months after surgery. On oblique coronal pre- (left) and postcontrast (right) T1-weighted (500/12) SE images, the periligamentous tissue shows moderate contrast enhancement in the joint and the tibial bone tunnel (arrowheads).

<table>
<thead>
<tr>
<th>Signal increase</th>
<th>Joint</th>
<th>Proximal tibial bone tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patellar</td>
<td>Hamstring</td>
</tr>
<tr>
<td>None</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Moderate</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Marked</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 17. Evaluation of periligamentous tissue contrast-enhancement on postcontrast T1-weighted images in Study IV.
Bone tunnel placement

In Study IV, one graft each in the patellar and the hamstring tendon group showed a slightly too far anteriorly placed (zone I) tibial bone tunnel. In each case, the signal of the intra-articular segment of the graft was intermediate on proton density- and T1-weighted images.

In Study V, of femoral bone tunnels in the symptomatic knee group, six (50%) were located too far anterior (five in zone III, one in zone II; Fig.11b). The tibial tunnel was too far posterior (zone III) in four (33%) knees (Fig.18b), and too far anterior (zone I) in three (25%) (Fig.19a). Graft impingement was evident in all three knees with too-anterior tibial tunnels (Fig.19b). In the asymptomatic knee group, all 14 knees had an optimal (zone IV) femoral tunnel position, whereas in two knees (14%) the tibial tunnel was positioned too posterior (zone III). Metal artifacts from fixation screws obscured bone tunnel visualization in two symptomatic knees. A significant difference existed between groups with respect to femoral bone tunnel position (P=0.005), but the difference in tibial bone tunnel position was non-significant (P=0.80). Sensitivity and specificity for femoral tunnel placement in predicting ACL deficiency was 60% (95% CI, 35-81%) and 100% (95% CI, 86-100%); and for tibial tunnel placement, 60% (95% CI, 35-81%) and 81% (95% CI, 61-92%).

All MRI findings together predicted ACL deficiency with a specificity of 90% (95% CI, 65-98%) and a sensitivity of 81% (95% CI, 61-92%).

Artifacts

In the patellar tendon group, artifacts from the metallic fixation screws totally obscured the femoral bone tunnel and partly obscured the tibial bone tunnel on all MR images. However, evaluation of graft integrity was not disturbed at the level of the joint space and the proximal tibial bone tunnel (except in the two knees in the symptomatic group). The hamstring tendon group had no imaging artifacts in the bone tunnels or the joint space, due to a more distal graft fixation technique.

Ancillary findings

In Study V, one symptomatic knee had a localized anterior arthrofibrosis (Cyclops lesion) (Figs.19c-d). One medial and one lateral meniscus rupture was detected, both in the
symptomatic group. Oblique sagittal STIR images showed minor joint effusion in six (43%) symptomatic and two (14%) asymptomatic knees, with marked effusion visible in one (7%) symptomatic knee.

In Study IV, two high signal intensity areas in the tibial bone tunnel consistent with a periligamentous cyst were visible on oblique sagittal STIR images in two cases in each group (Fig. 20c). In addition, the margins of the cyst showed moderate contrast enhancement in all four cases (Fig. 20b). In the hamstring tendon group, one periligamentous cyst with adjacent bone marrow edema was visible posterolateral to the tibial bone tunnel (Fig. 10c). Minor joint effusions were seen in four (40%) cases in the patellar tendon group and in two (20%) in the hamstring tendon group, but no patient in either group had a major effusion.

Figure 19. A 33-year-old male with knee instability symptoms (with no extension deficiency) 40 months after patellar tendon ACL reconstruction. In agreement with MRI findings, arthroscopy revealed a lax graft and anterior arthrofibrosis. Revision ACL surgery was indicated.

A. The tibial bone tunnel is placed too anterior (zone I), as evident on an oblique sagittal T2-weighted (2600/98) TSE image (asterisk).
B. On an oblique sagittal proton density-weighted (2600/16) TSE image, graft impingement is visible. The intra-articular segment of the graft shows a non-continuous localized area of intermediate signal intensity (arrow).
C. On an oblique sagittal STIR (5500/30/150) image, a focal nodular lesion of high signal intensity indicating anterior arthrofibrosis, a “Cyclops lesion” is visible anteriorly in the intercondylar notch (arrow).
D. On oblique coronal pre- and postcontrast T1-weighted (500/12) SE images, the arthrofibrosis shows marked signal enhancement (arrows).
A 33-year-old female patient from the patellar tendon group 38 months after surgery.

A. On an oblique coronal T1-weighted (500/12) SE image, a large cyst is detectable in the tibial bone tunnel.

B. On a postcontrast image, the margins of the cyst show marked contrast enhancement (arrowheads).

C. On an oblique sagittal STIR (5500/30/150) image, the cyst is visible posterior to the tibial bone tunnel with high signal intensity (arrowhead).

**Arthroscopic evaluation**

In the symptomatic group, arthroscopy revealed 12 (86%) abnormal (11 lax and one torn) and two (14%) normal grafts. All abnormal grafts underwent revision ACL surgery. In the two symptomatic knees with a normal graft, meniscus ruptures were visible (one medial and one lateral), and one normal graft was evident. The only repair was meniscal.

A summary of clinical evaluation, MRI, and arthroscopy findings is presented in Table 18.
### Table 18. Summary of Clinical Evaluation, MRI, and Arthroscopy Findings in Study V.

<table>
<thead>
<tr>
<th>Asymptomatic group (knee)</th>
<th>AP knee laxity, side-to-side difference (mm)</th>
<th>Femur zone (I-IV)</th>
<th>Tibia zone (I-IV)</th>
<th>Graft integrity on T2-images</th>
<th>Graft SI on T2-images</th>
<th>Enhancement of periligamentous tissue</th>
<th>Arthroscopy finding of the graft</th>
<th>Ancillary findings</th>
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</thead>
<tbody>
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<td></td>
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<tr>
<td>#1</td>
<td>*</td>
<td>IV</td>
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DISCUSSION

Surgical concepts

Graft options

Much debate continues in the current literature concerning the ideal method for ACL reconstruction. Among strong advocates for both patellar and hamstring tendon grafts, some suggest that the patellar tendon provides better stability, and others point to lower incidence of anterior knee pain with the hamstring tendon graft (Aune et al. 2001, Freedman et al. 2003, Johnson 2004, Matsumoto et al. 2006, Paessler et al. 2003).

A meta-analysis of over 2000 patients with patellar tendon or hamstring tendon ACL reconstruction with a minimum follow-up of 2 years concluded that patellar tendon autografts had a significantly lower rate of graft failure and resulted in better knee stability (Freedman et al. 2003). Patellar tendon autograft reconstructions resulted, however, in an increased rate of anterior knee pain. Our study found no major differences between patellar and hamstring tendon groups with respect to knee stability or anterior knee pain at the 2-year follow-up.

Aune’s group performed an RCT comparing patellar tendon-interference screw fixation to hamstring tendon–metal plate fixation. After 2 years of follow-up, a significant loss of knee flexion strength in the hamstring tendon group occurred (Aune et al. 2001). In our study, flexion strength was weaker in the hamstring tendon group, as expected, 1 year postoperatively, but at 2 years postoperatively, no difference appeared.

A recent RCT compared patellar and hamstring tendon ACL reconstructions with the same interference screw fixation method. With at least 5 years’ follow-up, results were comparable with respect to the IKDC classification, but the authors concluded that hamstring tendon grafts reduced the risk of problems at the graft harvest site compared to the risk with patellar tendon grafts (Matsumoto et al. 2006).

Some authors support the use of allograft tissue as one alternative in ACL reconstruction (Fu et al. 2000). Because the safety and efficiency of allograft materials have not been reported through RCTs, it is difficult to justify this material as a routine graft source for primary ACL reconstruction. In addition to allografts, reconstruction of ACL with synthetic material has not proven to be a satisfactory treatment for ACL-deficient knee (Beynnon et al. 2005b).

The long-term success of reconstructed ACL with patellar and hamstring tendon grafts is unknown. Yamaguchi’s group reported a 24-year follow-up using combined intra- and extra-articular ACL reconstruction with iliotibial tract. Of the surgical patients, 71% had moderate to severe degenerative changes on radiographs although about 50% participated in regular sports activities, and no patient required regular clinical intervention (Yamaguchi et al. 2006). There exists, therefore, concern about development of degenerative changes in the knee joint following ACL reconstruction. It is possible that ACL injury is not as benign as
earlier thought, and that degenerative changes cannot be totally prevented by ACL reconstruction (Ait Si Selmi et al. 2006, Harilainen et al. 2006).

According to our results, both patellar and hamstring tendon grafts are good choices for ACL reconstruction. No evidence indicates that one graft is more effective than another. More long-term RCTs that stratify patient populations into appropriate subgroups are needed to critically evaluate these ACL reconstruction techniques.

**Graft fixation**

Fixation of the graft represents the weakest link during the early stages after ACL reconstruction, and it seems that graft healing is an important factor in long-term success (Brand et al. 2000).

Studies using the patellar tendon in ACL reconstruction have reported no difference in clinical outcome with metallic, titanium, or bioabsorbable interference screws for graft fixation (Fink et al. 2000, Fu et al. 2000). In addition to the patellar tendon graft, our study demonstrated that hamstring tendon grafts can also be securely fixed with the interference screw technique.

Good results have been reported from the hamstring tendon graft with metal-plate, cross-pin or screw fixation techniques (Aune et al. 2001, Clark et al. 1998, Wilcox et al. 2005). With femoral metal plate or cross-pin fixation, the tibial side can be secured with screw- or post-fixation techniques. In a total of 47 cases in Studies I and II, the tibial fixation material (AO screw and post) was removed owing to patient discomfort. Despite such removal's being performed with minimal morbidity in the doctor’s office, it is possible that the optimal technique of hamstring graft fixation has yet to be identified.

Due to the complex anatomy and biomechanical function of the ACL, fixation of the hamstring tendon graft can also be achieved by double-tunnel ACL reconstruction. The proposed argument for double tunnel is that it may offer better rotational stability to the knee joint than does a single-tunnel reconstruction (Eriksson 2006, Woo et al. 2002). This biomechanical finding is, however, not supported by clinical trials using the double femoral tunnel technique in a 2-year follow-up (Adachi et al. 2004, Hamada et al. 2001).

**Bone tunnel enlargement**

Studies have reported that the bone tunnel diameter increase is significantly more accelerated within the first 6 weeks following ACL surgery than later. Minimal change occurs between 3 months and 2 years, and finally a decrease in tunnel diameter has been reported at 3 years after surgery (Fink et al. 2001, Harilainen et al. 2006, Peyrache et al. 1996).

In our study, bone tunnel enlargement after ACL reconstruction fell in the same range as that reported earlier (Colombet et al. 2002), and with no differences between the cross-pin and screw groups. The widening of tunnel edges was visible already by 1 year, and the well-defined sclerotic margins on radiographs suggest that the process had ceased.
In the hamstring graft-metal plate technique, despite the alarming appearance of bone tunnel enlargement in follow-up radiographs, MRI and clinical examinations as well as knee scores and laxity measurements confirm successful ACL reconstruction. Although the long-term outcome of enlarged bone tunnels is not yet known, such enlargement may complicate any possible ACL revision surgery. Future techniques and advances in primary ACL surgery should be able to eliminate this phenomenon.

**MRI features**

**Asymptomatic knees**

The MRI appearance of an asymptomatic ACL-reconstructed knee varies depending upon graft type, fixation technique, and time interval after surgery (Frick et al. 2006, White et al. 2005).

Our study reported the MRI appearance of asymptomatic patellar and hamstring tendon grafts 2 years after surgery: The ACL graft was continuous and showed homogeneous, low signal intensity on T2-weighted images. Its appearance was variable in proton density and T1-weighted images, however.

Several factors are identifiable causes of intermediate intra-articular signals on short echo-time images. Proposed causes are the magic angle effect, incomplete graft maturation, graft impingement, bone tunnel enlargement, and imaging artifacts (Echigo et al. 1999, Howell et al. 1991a, Howell et al. 1995, Murakami et al. 1998, Murakami et al. 1999).

On MRI, the magic angle effect is a well-known artifact. When ligaments are aligned at 55 degrees to the main magnetic field, the focal signal is increased on short echo-time MR images. This effect is caused by changes in the dipolar interactions between water hydrogen protons that are loosely bound along collagen fibrils in ligaments (Erickson et al. 1993). In a study by the Echigo group, their 40 patients underwent MRI with the knee in extension and flexion. They suggested the signal intensity changes in the ACL graft can be related to changes in its alignment and are likely a result of the magic-angle effect (Echigo et al. 1999). In spite of this, the magic angle effect is a less likely explanation for the intermediate signal intensity areas in our study, because all knees were in extension, with the ACL graft oriented significantly less than 55 degrees to the main magnetic field.

Maturation of the ACL graft demonstrates a variety of MRI findings such as high signal intensity areas in the intra-articular segment (Murakami et al. 1998, 1999). In these two studies, the entire hamstring graft became a low signal-intensity bundle after 12 months in proton density weighted SE images. Histological evidence shows that by 12 months after autogenous ACL reconstruction, the graft resembles an intact ACL (Johnson 1993). Thus, graft maturation in the intra-articular segment and in the tibial bone tunnel should be complete 12 months after surgery, and show low signal intensity on proton density weighted images.

Impingement of the graft by the intercondylar roof has been reported to cause increased signal intensity in the intra-articular segment (Howell...
et al. 1991a, 1995) In these two studies, patellar and hamstring grafts showed low signal intensity on proton density weighted images when the intra-articular segment of the graft was free from impingement by the intercondylar roof. On the other hand, they stated that increased intra-articular signal intensity on proton density weighted images in the distal two-thirds of the graft was caused by placement of the tibial bone tunnel too far anteriorly. This was associated 1 to 3 years after surgery with a greater incidence of instability and lack of full knee extension. In our study, a similar signal increase in the intra-articular segment of the graft was visible in 10 of 20 cases on proton density and T1-weighted images, although all patients had a successful outcome with no clinical evidence of impingement 2 years after surgery.

Both patellar and hamstring tendon autografts may show focal intermediate signal intensity areas on proton density and T1-weighted images 2 years after successful ACL reconstruction. This is a non-specific finding and does not signify ACL instability. The interpreting radiologist and the clinician treating the patient should be aware of these MRI features of the commonly used autografts in an asymptomatic postoperative knee.

**Symptomatic knees**

MRI plays an important role in the assessment of the symptomatic ACL reconstructed knee. MRI can demonstrate graft failure, bone tunnel position, impingement, and arthrofibrosis, as well as other causes of unsatisfactory outcome (McCauley 2005, White et al. 2005).

In our study, the femoral bone tunnel in the symptomatic knee group was placed significantly more anterior. In addition, only 3 symptomatic knees showed an optimal position. In one of the three symptomatic knees with an optimal position (knee #28), a meniscus rupture probably caused the symptoms. In one symptomatic knee (#21), however, we found on MRI no evidence of graft laxity in respect to graft continuity, signal intensity or bone tunnel placement. Despite this single case, and confirmed by the current literature, we believe that for good clinical outcome correct femoral bone tunnel position is of prime importance.

An intact graft seen on MRI can also be functionally deficient. In T2-weighted MR images, all 14 grafts in the asymptomatic group, but also 6 (43%) grafts in the symptomatic group showed a continuous, low signal-intensity graft. In five of these six grafts in the symptomatic group, however, the arthroscopic diagnosis was lax graft, with ACL revision surgery necessary. Based on these results, symptomatic ACL deficiency can be present even when an intact graft is visible on T2-weighted images. In these cases, identification of the incorrect placement of the bone tunnels can be the only finding suggesting ACL deficiency.

Static anterior drawer techniques have been introduced to stress the graft during MRI (Donell et al. 2006). This technique may give additional information on ACL insufficiency. However, the value of this new method is not yet established with ACL grafts and needs to be clarified.

MRI allows direct evaluation of the ACL graft, the bone tunnels, and of
additional disorders of the knee. Awareness of the range of MRI findings regarding complications after ACL reconstruction is essential for correct interpretation.

**Contrast enhancement**

Contrast enhancement provides additional information regarding the perfusion and vascularization of the ACL graft (Bach et al. 2002, Vogl et al. 2001). In our study, however, although the graft itself did not enhance, the periligamentous tissues showed contrast enhancement. Symptomatic knees showed contrast enhancement 4 to 84 months after patellar tendon ACL surgery. In asymptomatic knees, enhancement was seen 26 to 38 months after surgery in the patellar tendon group and 23 to 35 months after surgery in the hamstring tendon group.

According to these findings, enhancing periligamentous tissue is a non-specific finding and does not signify ACL deficiency. Contrast enhancement, however, allows better delineation of the entire length of the ACL graft on T1-weighted images. We do not, however, recommend the routine use of contrast media in imaging of the reconstructed ACL.

**Cystic degeneration**

A late complication of ACL reconstruction that is usually accompanied by bone tunnel enlargement is cystic degeneration of the graft. It has not been shown to correlate with graft failure or knee instability, but, if large, it may cause pain and some limitation of motion. Cysts most commonly arise within the tibial bone tunnel and may propagate and protrude into the joint proximally or into the subcutaneous soft tissues through the distal opening of the tibial tunnel (Schatz et al. 1997, Tsuda et al. 2006, White et al. 2005).

In our study, the cysts seen adjacent to the tibial bone tunnel had adjacent bone marrow edema, and may be due to ingress of synovium and synovial fluid into the bony tunnel (Murakami et al. 1999). It should be noted that such cystic degeneration may be present in a clinically stable symptom-free postoperative knee. We do not know if these MRI features indicate early signs of degeneration, which in due course would lead to graft failure. Therefore, additional postoperative studies with a follow-up greater than 2 years, using MRI with histopathological correlation, are necessary for us to fully understand the role of these MRI features in asymptomatic ACL reconstructed knees.

**Arthrofibrosis**

After ACL reconstruction, an important cause for knee extension deficiency is localized anterior arthrofibrosis (cyclops lesion), a fibrous nodule with granulation tissue located anterior to the tibial tunnel (Shelbourne et al. 1996). The etiology of anterior arthrofibrosis appears to be multifactorial (Delince et al. 1998). The fibroproliferative nodule may arise from the drilling debris of the tibial tunnel, the remnants of the native ACL, broken graft fibers, or from hypertrophied graft caused by impingement. Treatment is usually an arthroscopic resection (Delince et al. 1998).

Localized anterior arthrofibrosis can be depicted on MRI and arthrography (Bradley et al. 2000, McCauley et al. 2003, Sheldon et al.
2005). On T1-weighted MR images, it appears as a focal nodular lesion of low signal intensity that is anterior to the graft in the intercondylar notch and can be indistinguishable from adjacent joint fluid. On T2-weighted images, the nodule is heterogeneous but predominantly of low signal intensity and is well differentiated from high signal intensity joint fluid (Recht et al. 1995). In our study, anterior arthrofibrosis was visible in one symptomatic knee as a focal nodular lesion of high signal intensity on STIR images. Following contrast media infusion, this arthrofibrosis also showed moderate signal enhancement on T1-weighted images.

Imaging protocol

MRI techniques utilized in the evaluation of reconstructed ACL vary widely. In our study, the MR imaging planes were tailored for evaluation of the ACL graft, the bone tunnels, and of additional disorders of the knee. We used T2-weighted TSE images to determine graft integrity. Proton density TSE images and T1-weighted SE images add anatomical and morphological characteristics and can serve to demonstrate additional complications. Bone tunnel placement can be evaluated in the oblique sagittal and oblique coronal planes.

Modern MRI equipment offers new sequences, higher resolution, thinner slices, and the opportunity for 3-D imaging, but at the time of planning our imaging protocol, no such equipment was available. Today, we obtain immediate postoperative radiographs to evaluate the position of orthopedic hardware and to exclude the presence of iatrogenic foreign bodies. Our present MRI protocol after ACL reconstruction includes:

- oblique sagittal proton density and fat-suppressed T2-weighted TSE images
- oblique coronal T1-weighted SE and fat-suppressed T2-weighted TSE images
- axial fat-suppressed T2-weighted TSE images

If there is a substantial metal artifact in the knee, STIR images are used instead of fat-suppressed T2-weighted TSE images. For a specific indication after evaluation of the basic imaging protocol, contrast media can be injected.

Limitations

In our randomized material in Studies I and II, one limitation was the MCL and meniscal injury in addition to the ACL tear. The effects of other knee injuries complicate the treatment and outcome of ACL deficiency. It is difficult to find patients with solitary ACL tears lacking any other intra-articular lesions, but, the additional injuries seemed to be evenly distributed between the two groups.

Another limitation of Study I was that patellar and hamstring tendon grafts could not be compared to each other, because the fixation techniques differed.

In Studies III and IV, a limitation was the lack of an objective correlative standard to confirm the clinical status of the ACL graft. No second-look arthroscopy was not performed, so we cannot confirm that all grafts were intact, even
though all patients were asymptomatic. The knees, however, were stable and grafts were intact in MRI.

**Future trends**

The field of orthopedic surgery is currently in an exciting era. Advances in molecular biology, gene therapy, and tissue engineering in conjunction with robotic technology and computer-assisted surgery may allow orthopedic surgeons to more successfully restore the ACL-insufficient knee preinjury state. An increasing variety of well-established techniques and graft materials are being released to the market after laboratory testing of variable quality. Only after widespread use of these implants are clinical follow-up reports usually available.

A well-performed clinical examination with radiographs remains the basic tool in routine evaluation of the postoperative reconstructed ACL. MRI, however, plays a more crucial role in the evaluation of patients with recurrent or residual symptoms after ACL reconstruction, revealing surgical complications, reinjuries, or other sources of symptoms. Modern MRI equipment with higher field strengths and thinner slices are becoming more common in clinical practice, but the role of new imaging techniques is not yet established and needs to be clarified.
CONCLUSIONS

1. No major differences appeared in 2-year clinical outcome between patellar tendon-interference screw fixation and hamstring tendon-metal plate fixation, or between hamstring tendon cross-pin and interference screw fixation techniques. All techniques appear to improve patients’ performance and are therefore good choices for ACL reconstruction. There exists, however, a need for further research involving long-term, good-quality RCTs to fully assess these techniques’ effectiveness.

2. Bone tunnel enlargement occurs after hamstring tendon-metal plate ACL reconstruction. Despite successful ACL reconstruction based on MRI and clinical examinations, the long-term outcome of this phenomenon remains unknown. Bone tunnel enlargement may be clinically significant in revision surgery because such enlarged tunnels may complicate graft placement and fixation.

3. MRI permits direct evaluation of ACL graft, bone tunnels, and additional disorders of the knee. Recognizing the appearance not only of complications, but also of the asymptomatic findings after ACL reconstruction is essential for the radiologist and the clinician.

4. The most important technical consideration in achieving optimal results of ACL reconstruction is correct positioning of the bone tunnels. When an intact graft and optimal femoral bone tunnel position is apparent on T2-weighted images, graft deficiency is unlikely without new trauma, and the MRI examination should be carefully scrutinized for possible other causes for a patient’s symptoms.

5. After ACL reconstruction, enhancing periligamentous tissue can be apparent. Patellar and hamstring tendon grafts may show focal intermediate signal intensity areas on proton density and T1-weighted images. These are, however, non-specific findings, not signifying ACL instability.
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Finally, and most of all, I express my warmest thanks to my wife Jonna for her love and support, and to our twins Maisa and Julius for never letting me forget what is really important in life.

Helsinki, December 2006
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