



ANNA-STINA MOISALA

Arthroscopic Anterior Cruciate Ligament Reconstruction
with a Hamstring Autograft

Reconstruction technique, graft placement
and muscle performance



ACADEMIC DISSERTATION

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ACADEMIC DISSERTATION

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List of Original Communications

This thesis is based on the following original communications, referred to as study I-V in the text.

- I Moisala A-S, Järvelä T, Kannus P, Järvinen M (2007): Muscle strength evaluations after ACL reconstruction. *Int J Sports Med* 28: 868-872.
- II Moisala A-S, Järvelä T, Harilainen A, Sandelin J, Kannus P, Järvinen M (2007): The effect of graft placement on the clinical outcome of the anterior cruciate ligament reconstruction: A prospective study. *Knee Surg Sports Traumatol Arthrosc* 15: 879-887.
- III Moisala A-S, Järvelä T, Honkonen S, Paakkala A, Kannus P, Järvinen M (2007): Arthroscopic anterior cruciate ligament reconstruction using a hamstring graft with interference screw fixation. *Scand J Surg* 96: 83-87.
- IV Järvelä T, Moisala A-S, Sihvonen R, Järvelä S, Kannus P, Järvinen M (2008): Double-bundle anterior cruciate ligament reconstruction using hamstring autografts and bioabsorbable interference screw fixation. Prospective, randomized clinical study with two-year results. *Am J Sports Med* 36: 290-297.
- V Moisala A-S, Järvelä T, Paakkala A, Paakkala T, Kannus P, Järvinen M (2008): Magnetic resonance imaging of the bioabsorbable compared to metal screw fixation after ACL reconstruction with a hamstring autograft: a randomized clinical trial. *Knee Surg Sports Traumatol Arthrosc* (submitted)

Abbreviations

ACL	Anterior cruciate ligament
AM	Anteromedial
AP	Anterior-posterior
BTB	Bone-patellar tendon-bone
DB	Double-bundle
HQ	Hamstring-to-Quadriceps
IKDC	International Knee Documentation Committee
ML	Mediolateral
MRI	Magnetic Resonance Imaging
PCL	Posterior cruciate ligament
PL	Posterolateral
PLLA	poly-L-lactic acid
PLLA/HA	poly-L-lactic acid/hydroxyapatite
QSTG	Quadrupled semitendinosus and gracilis
RCT	Randomized controlled trial
SB	Single-bundle
SBB	Single-bundle with bioabsorbable screws
SBM	Single-bundle with metallic interference screws
SD	Standard deviation
STG	Semitendinosus and gracilis
TMC	Trimethylene carbonate

Abstract

The objective of this thesis was to evaluate the clinical outcome of the anterior cruciate ligament (ACL) reconstruction with a hamstring autograft. The associations of the graft placement, muscle strength, and the condition of the knee at the time of the operation with the clinical outcome were studied. Also, the prevalence of osteoarthritis in mid-term and the factors associated with it were characterized. In addition, in a prospective, randomized study, a novel double-bundle reconstruction technique was compared to a conventional technique, and magnetic resonance imaging (MRI) was used to evaluate the outcome of bioabsorbable versus metal screw fixation.

Patients' clinical assessment included evaluation of the anteroposterior and rotational knee stability, and the knee scoring system of the International Knee Documentation Committee (IKDC). The anteroposterior stability testing was done with a KT-1000-arthrometer. The subjective-functional assessment of the knee was done by a Lysholm knee score, and patients' activity level was evaluated using the Tegner score. The functional performance of the knee was evaluated using the "one-leg-hop"-test, and muscle strengths of the lower extremities were measured by Dynacom testing apparatus. The radiographic knee assessment of the osteoarthritic changes and ACL-graft placement was done. MRI was used to study the extent of graft-tunnel widening, absorption of the bioabsorbable screws, and possible adverse tissue reactions.

The study I showed that the muscle strength deficits at the injured lower extremity persisted even 3 to 7 years after the ACL reconstruction. However, they seemed to recover with time, especially the quadriceps strength of the patients with a bone-patellar tendon-bone (BTB) autograft. This suggested that in BTB patients the quadriceps strength was lower postoperatively compared to those treated with a hamstring autograft. The knee flexion (hamstring), and knee extension (quadriceps) strength deficits were associated with the subjective Lysholm score indicating that the smaller the strength difference between the operated and the non-operated limb, the less the patient experienced symptoms in the knee. Also, the knees with no instability had less flexion torque deficit than the knees with nearly normal or abnormal stability.

The study II revealed a correlation between the femoral graft position and the Lysholm score, so that the more posterior the graft was placed, the higher was the score. Simultaneous evaluation of the femoral and tibial graft placements proved useful by predicting both the anteroposterior and rotational stability of the knee.

The study III showed that meniscectomy at the time of the ACL reconstruction resulted in more severe osteoarthritic changes in the knee than reconstruction without meniscectomy. Also, the Lysholm score was higher when meniscectomy was not done.

The prospective, randomized study IV comparing a novel double-bundle ACL-reconstruction technique to a conventional single-bundle technique indicated that the new technique resulted in better rotational stability of the knee and was able to protect the patients from a reinjury-induced graft failure. No between-groups difference was noted in the occurrence of complications, or IKDC or Lysholm scores.

The study V showed that postoperative femoral tunnel widening was larger with the bioabsorbable screws than metal

screws, as judged with the MRI 2-years postoperatively. In the tibia, no difference was noted. The use of bioabsorbable screws resulted in more graft failures compared to the use of metal screws. After excluding the graft failures, the clinical outcome of the patients was equally good in the two groups. The follow-up tibial tunnel diameter correlated with the stability.

In conclusion, the studies I-V of this thesis showed that muscle strength deficits in the injured extremity 6 years after the ACL reconstruction were associated with inferior clinical outcome of the patient. However, the muscular performance seemed to improve by time, also in long-term. The graft placements (as assessed by simultaneous evaluation of the femoral and tibial graft placements) had an effect on both anteroposterior and rotational knee stability so that optimal graft positioning improved the stability. More severe osteoarthritic changes could be expected in the knees showing accompanying meniscal injury at the time of the reconstruction. A new double-bundle ACL reconstruction technique resulted in better rotational stability of the knee than the conventional single-bundle technique, and, it seemed to protect the knee from reinjury-induced graft failures. Finally, the use of bioabsorbable screws with the single-bundle technique resulted in larger femoral tunnel widening than the use of metal screws, and more graft failures.

Tiivistelmä

Tämän tutkimuksen tarkoitus oli arvioida hamstring-jännesiirteellä tehdyn polven eturistisiteen rekonstruktion paranemistulokset. Samalla tutkittiin siirteen paikan, lihasvoimien, sekä polven leikkaushetkisen kunnan yhteys paranemistuloksiin. Lisäksi kartoitettiin leikkauksenjälkeisen nivelrikon esiintyvyys sekä siihen liittyvät tekijät. Prospektiivisessa randomoidussa tutkimuksessa verrattiin uutta eturistisiteen tuplasiirreteknikkaa perinteisesti käytettyyn yhden siirteen tekniikkaan. Magneettitutkimuksella (MRI) arvioitiin biosulavien ruuvien ja metalliruuvikiinnityksen eroja paranemistuloksissa.

Käytetyt arviointimenetelmät sisälsivät ensisijaisesti polven kliinisen tutkimisen mukaan lukien polven väljyyden eli instabiliteetin arviointi (etu- ja kiertosuunta) ja arvio polven toimintakyvystä International Knee Documentation Committee (IKDC)-luokituksen mukaisesti. Polven väljuus etusuuntaan mitattiin myös KT-1000-mittarilla. Lisäksi käytettiin subjektiivista Lysholmin arviointipisteitystä, ja potilaiden aktiivisuustaso arvioitiin Tegner-luokituksen avulla. Alaraajojen toimintatestaus suoritettiin ´yhden-jalan-hyppy´-testillä, ja lihasvoimamittaukset suoritettiin Dynacom-laitteella. Röntgenkuvista arvioitiin nivelrikkomuutokset ja siirteen paikka. MRI:tä käytettiin tutkittaessa siirretunnelin laajenemista ja biosulavien ruuvien häviämistä, sekä mahdollisia haittavaikutuksia.

Tutkituilla potilailla oli lihasvoimapuutoksia edelleen 3-7 vuotta polven eturistisiteen korjausleikkauksen jälkeen, tosin

voimavajaus näytti pienenevän ajan myötä. Erityisesti polven ojentajalihaksen voima BTB-siirteen saaneilla potilailla näytti paranevan, mikä viittaa siihen, että näillä potilailla leikkauksenjälkeinen polven ojentajalihaksen voima oli alempi verrattuna hamstring-siirteen saaneisiin potilaisiin. Polven koukistaja- (hamstring) ja ojentajalihasten (quadriceps) voimapuutokset korreloivat subjektiivisen Lysholm-arvion kanssa siten, että mitä vähemmän potilaalla oli eroa näissä lihasvoimissa leikatun ja ei-leikatun jalan välillä, sitä vähemmän potilas koki polven oireita. Lisäksi tukeviksi luokitetuissa polvissa oli vähemmän koukistusvoiman vajetta kuin polvissa, joissa oli vain ”lähes normaali” tai ”epänormaali” tukevuus.

Femoraalisen siirteen paikan ja Lysholm-arvion välillä huomattiin yhteys siten, että mitä taaemmaksi reisiluuta siirre oli asetettu, sitä korkeampi oli Lysholm-arvio. Femoraalisen ja tibiaalisen siirteen paikan yhtäaikainen arviointi osoittautui hyödylliseksi ja niistä tehty summapisteytys ennusti polven tukevuutta sekä etu-taka (AP)- että kiertosuuntaista voimaa vastaan.

Polvissa, joista oli poistettu osa kierukkaa eturistisiteen korjausleikkauksen yhteydessä, oli jälkitarkastuksessa enemmän polven kulumamuutoksia verrattuna polviin, joihin ei oltu tehty kierukan osapoistoa. Myös Lysholm-arvio oli korkeampi silloin, kun kierukan osapoistoa ei ollut tehty.

Prospektiivisessa, satunnaistetussa tutkimussarjassa verrattiin eturistisiteen rekonstruktion uutta tuplasiirretekniikkaa perinteisempiin tekniikoihin. Tulokset viittasivat siihen, että uusi leikkaustekniikka johti parempaan polven kiertosuuntaiseen tukevuuteen, sekä suojasi vanhaa tekniikkaa paremmin uusintavamman aiheuttamalta siirteen pettämiseltä. Leikkauskomplikaatioissa, IKDC tai Lysholm arvioinneissa ei ollut eroja näiden ryhmien välillä.

Kahden vuoden kuluttua leikkauksesta MRI:llä arvioituna leikatuissa polvissa tapahtui enemmän femoraalista tunnelin laajenemista, kun käytettiin biosulavia ruuveja verrattuna metalliruuveihin. Biosulavien ruuvien käyttö johti useammin siirteen peittämiseen kuin metalliruuviin käyttö. Kun potilaat, joiden siirre oli peittänyt, jätettiin pois analyysistä, potilaiden kliiniset paranemistulokset olivat yhtä hyvät kummassakin ryhmässä. Seuranta-ajan jälkeinen tibiaalisen tunnelin läpimitta korreloi polven tukevuuteen.

Yhteenvedona tästä tutkimuskokonaisuudesta voitiin todeta, että ACL-rekonstruktiopotilailla on lihasvoimavajauksia vielä 6 vuotta leikkauksen jälkeen, joskin voimavajaukset näyttävät pienenevän ajan myötä. Yhden siirteen leikkaustekniikkaa käytettäessä sekä femoraalisen että tibiaalisen siirteen paikan yhtäaikainen arviointitulokset korreloi sekä etu-takasuuntaisen että kiertosuuntaisen stabiliteetin kanssa. Polvissa joissa oli kierukkavamma ACL-korjausleikkauksen aikaan, on odotettavissa enemmän polven kulumamuutoksia. Eturistisiteen rekonstruktion uusi tuplasiirreteknikka näyttää johtavan parempaan polven kiertosuuntaiseen tukevuuteen kuin yhden siirteen leikkaustekniikka. Se näyttää suojaavan polvea myös uusintavamman aiheuttamalta siirteen peittämiseltä. Biosulavien ruuvien käyttö yhden siirteen tekniikassa johtaa suurempaan femoraalisen tunnelin laajenemiseen kuin metalliruuviin käyttö, sekä useammin siirteen peittämiseen.

Introduction

An anterior cruciate ligament (ACL) tear of the knee is one of the most common sports injuries. It often leads to instability of the knee especially during exercise or heavy work, and in such cases usually requires surgical treatment. The treatment of choice is reconstruction using most commonly either a bone-patellar tendon-bone autograft or a quadrupled semitendinosus and gracilis (hamstrings) tendon autograft. The purpose of ACL reconstruction is to restore normal stability, and to protect the knee from further injury. (Beynnon et al. 2005a)

In recent years, new reconstruction techniques have been developed. These aim to better restore the kinematics of the knee, and thus possibly to protect the knee from recurrent injury, meniscal tear and concomitant osteoarthritis (Järvelä 2007).

The evaluation methods of ACL reconstruction include full clinical examination of the injured extremity including evaluation of the anteroposterior and the rotational stability of the knee, anteroposterior stability testing with an arthrometer, functional testing, subjective knee scores, evaluation of the patient's activity level, International Knee Documentation Committee (IKDC) score (which is based on clinical examination), lower extremity muscle strength testing, and radiological and MRI evaluations.

The first aim of this thesis was to evaluate the role of a concomitant meniscal injury at the time of the ACL reconstruction and postoperative muscle atrophy to the clinical outcome of the patient. We also explored whether the graft placement (femoral and tibial, and both of these simultaneously) had effect on the

clinical outcome of the patient. A third goal was to evaluate the clinical outcome of a new double-bundle reconstruction technique of the ACL since novel procedure was thought to better restore the anatomy of ACL and kinematics of the entire knee than the conventional single-bundle technique. Finally, MRI of the knee was used to compare bioabsorbable and metal screw fixation in ACL reconstruction, and these findings were correlated to the clinical outcome of the patients.

Review of the Literature

1. Anatomy of the ACL

The ACL is a band of dense connective tissue, which courses from the femur to the tibia. Micro-anatomically and histologically it is one structure (Danylchuk et al. 1978, Odensten & Guillquist 1986). The ACL runs from the posteromedial aspect of the intercondylar notch on the lateral femoral condyle anteriorly, medially, and distally (Duthon et al. 2006).

The cross-sectional shape of the ACL is not circular, elliptical or any other simple geometrical form. This shape changes with the angle of flexion, but is generally larger in the anterior-posterior direction. The narrowest part of the ACL is at mid-substance level (35 mm²). (Duthon et al. 2006)

The ACL fibers fan out as they approach their tibial attachment. They attach to a fossa located anterior and lateral to the medial tibial spine. This fossa is a wide, depressed area approximately 11 mm wide (range, 8–12 mm) and 17 mm (range, 14–21 mm) in the antero-posterior direction. Near its attachment some extensions may blend with the attachment of the anterior or posterior horn of the lateral meniscus. The tibial attachment is somewhat wider than the femoral attachment. The tibial ACL insertion begins approximately 10 to 14 mm from the anterior border of the tibia and extends to the medial and lateral tibial spine. (Duthon et al. 2006, Girgis et al. 1975, Petersen & Zantop 2007)

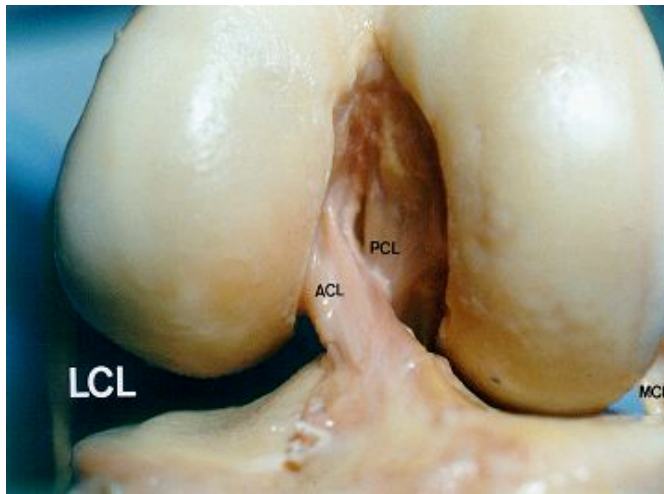


Figure 1. *The anterior cruciate ligament attaches to the anterior intercondylar fossa in front of the intercondylar eminence (the tibial spine), and blends with the anterior horn of the lateral meniscus.*

Functionally, Girgis et al. (1975) divided the ACL into two parts, the anteromedial (AM) bundle and the posterolateral (PL) bundle named for the orientation of their tibial insertions. This anatomy is already well seen in a fetus (Ferretti et al. 2007). Amis and Dawkins (1991) measured changes in fibre length during knee flexion/extension, and found that the fibre bundles are not isometric. The PL bundle is tight in extension and loosens in flexion after its femoral origin moves anteriorly, whereas the AM is tight in flexion and becomes lax as its femoral insertion moves posteriorly during extension.

However, the anteromedial bundle is the part of an intact ACL with the least length change during passive extension-flexion of the knee (Amis et al. 1994). Furman et al. (1976) showed that transection of the anteromedial bundle caused a positive anterior drawer sign and a negative Lachman sign, while the converse was

true for the posterolateral bundle. This suggests that partial ruptures can affect different bundles, depending on the posture at the time of injury.

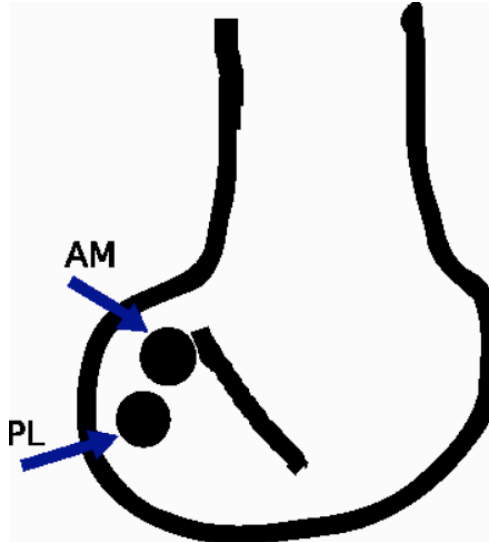


Figure 2. *The mean length of the femoral ACL insertion is 18 mm and the mean width is 11 mm. The distance between the centers of the AM and PL bundles varies between 8 and 10 mm. (Petersen & Zantop 2007)*

2. Biomechanics of the ACL

The motion characteristics of the articular surfaces of the tibia relative to the femur are very complex and are guided by the ACL and the other primary ligaments that span the knee (Beynon et al. 2005a). The primary function of the ACL is to prevent anterior displacement of the tibia relative to the femur (Butler et al. 1980, Fukubayashi et al. 1982). It also acts as a restraint to internal-external rotation (Fleming et al. 2001, Kanamori et al. 2002, Markolf et al. 1990), varus-valgus angulation (Marder et al. 1991), and combinations thereof (Kanamori et al. 2002, Markolf et al. 1995).

Biomechanical studies show that the PL bundle plays a significant role in the stabilization of the knee against a combined rotatory load. Biomechanical studies have shown that standard single-bundle ACL reconstructions are successful at restoring anterior stability to the knee, but not the rotatory stability in all knees, as one would see with a pivot shift phenomenon (Woo et al. 2002). Even though the knee is stable in anterior-posterior direction after reconstruction using a single-bundle technique, internal rotation of the tibia occurs e.g. during squatting (Logan et al. 2004) and running (Tashman et al. 2004). When considering the most common injury mechanisms, the ability of the ACL graft to resist combined valgus and internal tibial torques is equally important to consider as its ability to resist anterior-directed loads.

The Quadriceps muscle functions as an ACL antagonist causing strain to the ACL when it contracts with the knee near extension (DeMorat et al. 2004, Fleming et al. 2001). The

hamstring muscles function as ACL agonists throughout the range of knee flexion, and thus protect the ACL (O'Connor 1993).

3. Incidence of ACL injury

The annual incidence of isolated ACL injury has been reported to be 30/100 000 persons, and that of a combined ACL injury 98/100 000 persons (Daniel et al. 1994, Miyasaka et al. 1991) at physically active populations. Accompanying injuries include other ligament sprains, meniscal tears, articular cartilage injuries, bone bruises, and sometimes intra-articular fractures (Beynon et al. 2005a). The incidence of ACL tears depends on the type of sport, and more injuries occur during a game than in training. These sports with a high-risk to sustain an ACL injury include sports, which require the athlete to make sudden decelerations, accelerations, and other unanticipated running and cutting maneuvers. (Griffin et al. 2006)

There are some studies reporting exact incidence rates of ACL injury in different sports. The incidence of ACL injury in handball among men was 0.24 per 1000 game hours, and among women 0.77 per 1000 game hours in the study of Olsen et al. (2003). With women the incidence rate of ACL injuries in soccer was 0.6 per 1000 game hours (Tegnander et al. 2008), and in floorball 3.6 per 1000 game hours according to Pasanen et al. (2007).

Gwinn et al. (2000) reported the ACL injury rates per 1000 athlete-exposures (one athlete-exposure is defined as one athlete participating in one practice or game where he or she is exposed to the possibility of an athletic injury). In soccer, the incidence of ACL injury was 0.8 per 1000 athlete-exposures among women and 0.1 per 1000 athlete-exposures among men intercollegiate

athletes. In basketball, the injury rates were 0.5 among women and 0.1 among men, respectively. (Gwinn et al. 2000)

The injury risk is 2.4 to 9.7 times higher for female athletes compared to male athletes competing in similar activities (Arendt et al. 1999, Gwinn et al. 2000, Hewett et al. 2001, Myklebust et al. 1998, Stevenson et al. 1998). The female dominance has been explained by anatomical factors, such as greater quadriceps (Q) angle due to a wider pelvis which results in the knee being in a more valgus position (Griffin et al. 2006, Malinzak et al. 2001), smaller intercondylar notch (Anderson et al. 2001), differences in general laxity (Wojtys et al. 1998), hormonal changes attributed to the menstrual cycle (Wojtys et al. 1998), neuromuscular control of the quadriceps and hamstring muscles (Griffin et al. 2006, Malinzak et al. 2001, Sigward & Powers 2006), differences in the hamstring-to-quadriceps strength ratio (Anderson et al. 2001), and kinematics of the lower extremity (Malinzak et al. 2001). Women tend to perform cutting and twisting movements in a more erect posture than men (less knee flexion), and, when landing from a jump, men tend to activate their hamstring muscles first, whereas women rely more on the quadriceps femoris muscle (Griffin et al. 2006, Malinzak et al. 2001).

4. Injury Mechanism

The typical mechanism of injury is deceleration with twisting, pivoting, or a change of direction. It was estimated by Wilk et al. (1999) that at least 60% of all ACL injuries sustained by athletes are due to a non-contact mechanism of injury. Perhaps the most common mechanism for sustaining an ACL injury is a valgus stress with tibial external rotation at the knee joint with the knee flexed (Ebstrup & Bojsen-Möller 2000, Natri 1996). This

mechanism of ACL injury is especially common when the athlete lands from a jump (Wilk et al. 1999). Another common mechanism is a combination of internal rotation and varus strain with the knee flexed, typically occurring when the tibia is unable to move, as in team handball players on high friction artificial turfs (Ebstrup & Bojsen-Möller 2000, Natri 1996).

Other forced injury mechanisms have also been described, e.g. hyperflexion with internal rotation of the tibia, which typically occurs in down-hill skiing when the skier loses balance and sits far backward. This results in deep knee flexion while the weight is put on the inside edge of the downhill ski (the uphill ski is unweighted, and the uphill arm is placed backward out of the snow). Also, in downhill skiing, an injury resulting from a backward fall has been identified. This results in an ACL tear, when the top of the ski boot drives the tibia forward producing an anterior directed force on the tibia relative to the femur ('boot-induced anterior drawer'). A forward fall resulting in hyperextension or a combination of hyperextension and internal rotation of the tibia is another mechanism that has been described to lead to an ACL injury. (Järvinen et al. 1994, Natri 1996)

5. Natural history of the ACL-deficient knee and conservative treatment

The true natural history of the ACL-deficient knee has not been studied in a well-designed prospective cohort study (Beynnon et al. 2005a). Usually, an ACL tear results in functional instability, giving way symptoms, swelling of the knee and pain, especially during strenuous activity (Beynnon et al. 2005a, Fetto & Marshall 1980). The ACL-deficient patients are likely to develop further

intra-articular damage, i.e. meniscal tears (Bray & Dandy 1989, Keene et al. 1993), and osteoarthritis of the knee (Beynnon et al. 2005a, Kannus & Järvinen 1987). Conservative treatment of ACL tears leads to osteoarthritic changes evaluated by radiographs in 60 % to 90 % of patients 10 to 15 years after the index injury (Beynnon et al. 2005a, Lohmander & Roos 1994). The prevalence of osteoarthritic changes in radiographs taken of ACL-reconstructed knees has been reported to be between 35 % and 80 % (Lohmander & Roos 1994). There is currently not enough evidence of a possible protective role of ACL reconstruction with regard to long-term osteoarthritic development in the injured knee (Lohmander et al. 2007).

Based on an analysis on an administrative database, Dunn et al. (2004) suggested that an ACL reconstruction might be able to reduce additional operations, especially with young patients. They identified retrospectively a cohort of 6576 army personnel who had an ACL rupture. Of them, 3795 subjects (58 %) had an ACL reconstruction within 6 weeks, compared to 2781 subjects who did not (42 %). The rate of reoperation was significantly lower among the ACL-reconstruction group (32.7 % vs. 12.7 %) in the mean follow-up of 36 months. These reoperations were done due to a meniscal or cartilage injury, or a late ACL reconstruction was done because of instability symptoms. Also, young age was the strongest predictor of failure of conservative treatment.

There are no randomized controlled trials comparing conservative treatment to current surgical treatment options (Beynnon et al. 2005b, Linko et al. 2005). Meunier et al. (2007) compared primary repair (out-dated surgical method) with non-surgical treatment of ACL rupture in a quasi-randomized trial with a 15-year follow-up. Functional recovery was similar, and conservative treatment often gave acceptable recovery results. Some studies indicate that conservative treatment could be a good alternative in lower-demand populations with acute ACL injury,

and some of these patients are even able to participate in low-risk pivoting sports (Casteleyn & Handelberg 1996, Daniel et al. 1994, Linko et al. 2005, Strehl & Eggli 2007). However, Nebelung and Wuschech (2005) reported that in Olympic athletes who returned to high-level sports after an ACL tear, non-operative treatment led to severe osteoarthritis in 95 % of cases over 20 years of follow-up.

6. Reconstruction of the torn ACL

The purpose of the reconstruction is to restore normal function and stability of the knee and avoid further damage in the knee joint. Currently, indications for ACL reconstruction include a high-risk lifestyle including heavy work, sports, or recreational activities. Also, repeated episodes of giving-way in spite of rehabilitation are considered a strong indication for ACL reconstruction. (Beynnon et al. 2005a)

6.1. Graft material

Graft choices for ACL reconstruction include autografts and allografts. Also prosthetic materials have been introduced, but the failure rate has been too high, 48 to 78 per cent over a 15 year period according to the literature review done by Frank & Jackson (1997).

The ideal graft material would reproduce the complex anatomy of the native ACL, provide the same biomechanical properties of the native ACL, permit secure fixation, promote rapid biologic incorporation to allow for accelerated rehabilitation, and minimize donor site morbidity (Fu et al. 1999, Fu et al. 2000).

Currently, commonly used autogenous grafts include bone-patellar tendon-bone (BTB), quadrupled hamstring tendons (STG) and quadriceps tendon with or without bone. Allograft options include BTB, hamstring tendons, Achilles tendon, and anterior or posterior tibialis tendon (Prodromos et al. 2007). Soft tissue and BTB allografts result in lower level of stability (Prodromos et al. 2007), and higher failure rate than their autograft counterparts (Gorschewsky et al. 2005).

The postoperative complications when using a BTB graft include anterior knee pain, quadriceps weakness, patellar fractures and patellar tendon rupture (Järvelä et al. 2000, Kartus et al. 1997, Sachs et al. 1989). For many years, the BTB autograft has been advocated as the gold standard but the issues relating to donor site problems have led to the increased use of STG autografts. The disadvantages of the STG graft are weakness of hamstring muscle strength postoperatively and an increased risk of tunnel widening on the tibial side (Kobayashi et al. 2004, L'Insalata et al. 1997, Woo et al. 2006, Yasuda et al. 1995). Also, it has been advocated that the tendon-to-bone healing with the STG graft might be slower than bone-to-bone healing with the BTB graft (Woo et al. 2006). However, this seems to depend on the fixation material used, so that suspensory fixation leads to slower healing (Pinczewski et al. 1997, Robert et al. 2003).

The quadruple hamstring tendon graft has higher graft strength, stiffness and cross-sectional area compared to the BTB graft, and additionally, the extensor mechanism is preserved intact (Brown et al. 1993). On the other hand, Aglietti et al. (1994) reported that the patients with a BTB graft returned to sports participation more frequently than the patients with a STG graft.

In a recent meta-analysis of RCTs done by Goldblatt et al. (2005), a greater proportion of the patients who underwent reconstruction with a BTB graft had less than 3 mm side-to-side difference with the KT-1000 manual maximum test compared to

the patients with a quadrupled STG graft. Fewer patients with a STG graft had extension loss or patellofemoral crepitation. On the other hand, Prodromos et al. (2005), in their meta-analysis, found higher normal stability (≤ 2 mm instrumented Lachman test difference) rate and lower abnormal stability (> 5 mm) rate with the quadrupled STG compared to BTB autograft.

The article selection criteria were different in these two meta-analyses. Goldblatt et al. (2005) included only studies comparing the two graft materials, whereas Prodromos et al. (2005) included all ACL reconstruction studies that showed stratified stability data, and also took into account the fixation method; EndoButton femoral fixation resulted in the best stability.

TABLE 1.

The ultimate strength and stiffness of the native ACL and the most commonly used graft materials.

	Ultimate strength to failure (N)	Stiffness (N/mm)
Native ACL (Woo et al. 1991)	2160	242
Patellar tendon (Cooper et al. 1993)	2977	455
Quadrupled semitendinosus and gracilis (Hamner et al. 1999)	4140	807

6.2. Graft fixation

The ideal graft fixation provides sufficient strength and stiffness to allow current accelerated rehabilitation protocols with immediate full range of motion of the knee and full weight-bearing. Also, it is anatomic, biocompatible, safe and reproducible, allows undisturbed postsurgical magnetic resonance imaging (MRI) of the knee, and does not complicate possible revision surgery (Fu et al. 1999, Fu et al. 2000). From a biomechanical perspective, fixation represents the weak link during the early stages of healing. The long-term goal is to obtain biological incorporation of the graft at the anatomical attachment site of the ACL and to restore the transition from soft tissue to fibrocartilage, to calcified fibrocartilage, and to bone. (Beynnon et al. 2005b, Brand et al. 2000)

Several different fixation methods are currently available. Interference screws have been successful with grafts with a bone block at the end (with the BTB graft this has been the gold standard). This type of fixation can be at the articular surface (aperture fixation), and can thus limit the graft-tunnel motion. (Woo et al. 2006) Interference screws have also been used with soft tissue grafts with good results (Pinczewski et al. 2007).

Recently, several different bioabsorbable screws made of different materials have become available. These screws show no distortion in postoperative MRI. Also, ideally they would be replaced by bone in a relatively short time, and after this there is no need for removal in cases of revision or arthroplasty. The disadvantages include possible screw breakage during the insertion and inflammatory response associated with the degradation process (Böstman & Pihlajamäki 2000). Also, some materials have been very slow to degrade (Ma et al. 2004).

Bioabsorbable and metal screws have generally provided comparable initial fixation strengths in cyclic loading tests (Kousa et al. 2003a, Kousa et al. 2003b).

With the hamstring graft several different fixation methods have been used (Brand et al. 2000). Suspensory fixation (e.g. endobuttons, transfixion) fixes the graft further from the joint line and thus allows graft-tunnel motion to occur. For the tibial side, e.g. cortical screws and washers are used. The ultimate load of the fixation is around 800-900 N (Kousa et al. 2003b).

6.3. Graft placement

The optimal femoral tunnel placement should be within the anatomical attachment site of the ACL (Good et al. 1994). Both the frontal (o'clock) and the sagittal (lateral) directions have to be considered when placing the femoral tunnel for the graft. A too anterior femoral graft placement will tighten in flexion and thus restrict the movement and result in flexion loss, whereas a too posterior femoral attachment site leads to graft tightening in extension and slackening in flexion, and thus results in increased anteroposterior laxity in flexion.

During surgery, with the knee flexed, directions are often related to a clock face that is imagined to be placed in the notch. Placing the graft at 10 o'clock position has better restored the anterior laxity under rotational loading compared to the 11 o'clock position. However, no single position can produce the rotatory knee stability close to that of the intact knee. (Loh et al. 2003)

In the tibia, the graft should be placed in the crossing of the anterior horn of the lateral meniscus, and the tibial spine so that the anterior edge of the graft should be posterior to Blumensaat's line with the knee at 0 degree of flexion. A too posterior tibial placement leads to increased laxity, whereas a too anterior

placement will result in impingement of the graft against the roof of the femoral notch as the knee is brought into extension. (Amis et al. 1994, Amis & Dawkins 1991, Beynnon et al. 2005b, Good et al. 1994, Howell & Clark 1992)

6.4. Single-bundle vs. double-bundle reconstruction

In recent years, some surgeons have advocated a technique that restores the footprints of the AM and PL bundle through a “double-bundle” reconstruction. This can be achieved by making separate grafts from the gracilis and semitendinosus tendons and creating two tunnels (one for each graft) to femur and tibia (Aglietti et al. 2007, Järvelä 2007, Muneta et al. 2007, Yasuda et al. 2006, Yagi et al. 2007).

In vivo kinematics studies have confirmed the poor rotational control of single-bundle ACL reconstruction, especially towards extension, with a persistent tibial internal rotation similar to the ACL-deficient knee (Aglietti et al. 2007, Tashman et al. 2004, Ristanis et al. 2003, Ristanis et al. 2005).

As the double-bundle technique has increased in popularity, new approaches to the surgical treatment of partial ACL tears have also emerged. In a limited number of partial ACL tears, an intact AM or PL bundle may be observed. New surgical approaches allow for the preservation of the intact bundle, with surgical augmentation of the injured bundle (Ochi et al. 2006).

6.5. Postoperative concerns

Bone tunnel enlargement after ACL reconstruction occurs within the first months, and according to the study of Peyrache et al. (1996) the tunnel diameter decreases after 3 years when using a BTB graft with an interference screw fixation. This phenomenon seems to be related to the surgical technique (Höher et al. 1998, L'Insalata et al. 1997, Giron et al. 2005). So far, it has not been associated with increased laxity or graft failure (Aglietti et al. 1998, Clatworthy et al. 1999, Höher et al. 1998). It may, however, complicate graft placement and fixation in revision surgery (Wilson et al. 2004).

The etiology of tunnel enlargement is most likely multifactorial; these etiological factors have been divided into mechanical and biological factors (Wilson et al. 2004). Possible contributing factors to tunnel widening include graft-tunnel motion, synovial inflammatory response, localized bone necrosis caused by drilling, accelerated rehabilitation, use of allograft tissue, and malpositioning of the tibial tunnel (Höher et al. 1998, Wilson et al. 2004, Zijl et al. 2000).

The interference screw fixation to the joint line does not allow graft-tunnel motion. With the BTB autograft placing the bone block close to the joint line results in minimal tunnel widening (Aglietti et al. 1998). Similarly with the hamstring graft, a correlation between the incidence of tibial tunnel widening and the distance of the interference screw from the joint line was reported, so that the incidence of widening was smallest when the screw was closest to the joint (Giron et al. 2005). The extent of tunnel widening with bioabsorbable interference screws depends also on the screw material used (Robinson et al. 2006).

Thigh muscle atrophy often occurs after an ACL injury, and the extent of it is related to the length of ACL-deficiency prior to the reconstruction (Natri et al. 1996). In addition, the graft material has specific effects on muscle strengths. When a BTB autograft is used, the knee extension strength decreases postoperatively (Kobayashi et al. 2004), and the deficit is related to the activity of the patient and the intensity of the rehabilitation (Lephart et al. 1993). Harvesting the semitendinosus and gracilis tendons for graft material results in loss of knee flexion strength (the hamstring strength) postoperatively (Eriksson et al. 2001, Yasuda et al. 1995).

Muscle strengths are associated with the functional outcome of the patient (Kannus 1988). Thigh muscle weakness has been closely related to anterior knee pain and extension deficit when using a BTB autograft (Järvelä et al. 2000, Natri et al. 1996, Sachs et al. 1989). The hamstring muscles function as ACL protagonists thus protecting the ACL (Solomonow et al. 1987). A high Hamstring-to-Quadriceps (HQ) strength ratio might protect the patients from ACL injury (Hewett et al. 2001), and enable ACL deficient patients return to higher level in sports (Giove et al. 1983).

Aims of the Study

1. To compare the muscle strengths of patients operated using a BTB or a QSTG autograft and to evaluate their effects on the clinical outcome after a mid-term follow-up. (I)
2. To evaluate the effect of graft placement on the clinical outcome of the patient considering both the femoral and tibial graft placements. (II)
3. To investigate the mid-term clinical and radiological outcome after ACL reconstruction with quadruple STG autograft and interference screw fixation. (III)
4. To prospectively investigate the clinical outcome of a new double-bundle ACL reconstruction technique. The clinical results are compared to a single-bundle technique in a randomized study. (IV)
5. To prospectively compare the clinical outcome of patients randomized to receive either bioabsorbable or metal screw fixation with a quadruple hamstring graft, and to correlate the outcome to tunnel widening as evaluated by MRI. Also, the degradation of the bioabsorbable screws is evaluated by MRI. (V)

Patients and Methods

1. Patients

1.1. Study I

The basic population of this study comprised of all 150 patients who had ACL reconstruction at the Tampere University Hospital between 1997 and 2000. The reconstruction techniques used were bone-patellar tendon-bone graft or a quadruple hamstring graft with interference screw fixation. The inclusion criteria were: primary ACL surgery, closed growth plates and absence of ligament injury to the contralateral knee. The aim was to find patients to each group (BTB or hamstring), so that the patient groups would match according to the sex and age of the patients, and the length of the follow-up. Twenty-one patients with a BTB graft and 37 patients with a hamstring graft were initially selected and invited to the follow-up examination. Sixteen patients with a BTB graft and 32 patients with a hamstring graft were able to attend, a total of 48 patients.

Among the 48 patients were 39 men and 9 women. The clinical examination was conducted at a mean follow-up of 5 years 9 months (range, 3 years 8 months to 7 years 5 months). The BTB and hamstring groups were similar with regard to the sex and age of the patients, and the length of the follow-up. At the time of the surgery, 4 patients in the BTB group, and 9 patients in the hamstring group had a medial meniscal rupture, 9 of which were partially resected (4 in the BTB, and 5 in the hamstring group)

and 4 sutured. In addition, 11 patients had a lateral meniscal rupture (4 in the BTB, 7 in the hamstring group), 10 of them were partially resected (3 in the BTB, 7 in the hamstring group), and one sutured. Two patients (4 %) had a meniscal rupture in both menisci (included in the previous numbers).

During the follow-up period, one patient had a contralateral ACL injury, and 3 patients had a reinjury to their operated knee and these knees were unstable. These 4 patients were excluded from the follow-up calculations thus leaving 44 patients for the study.

1.2. Study II

All patients who underwent an arthroscopic ACL reconstruction with a hamstring graft at the Hospital Orton, Helsinki, Finland between 1998 and 2004 were included in this study, provided they had no other ligament injuries to the operated knee, closed growth plates, and no contralateral ACL injury. The 140 patients who fulfilled the inclusion criteria were followed up prospectively. There were 90 men and 50 women.

Eleven patients had revision surgery (previously, two patients ACL were sutured, seven had ACL reconstruction with a BTB graft, one patient with a STG graft, and one patient had an extra-articular reconstruction). Fourteen patients had bilateral ACL reconstruction done by the time of the follow-up. Mean age of the patients was 32 years at the time of the operation. One hundred and four (74 %) of the patients could be re-examined 2 years after the ACL surgery. One of these patients had suffered a reinjury to the operated knee before the 1-year follow-up and her knee was unstable. This patient was excluded from the current follow-up analysis thus leaving 103 patients for the study.

As an additional injury, 42 patients (30 %) had a medial meniscal rupture at the time of the ACL surgery. Of these, 31 patients (22 %) had a partial meniscectomy, 6 patients (4 %) had a complete meniscectomy, and in 2 (1 %) patients the meniscus was sutured. Also, 25 patients (18 %) had a lateral meniscal rupture, 16 patients (11 %) had a partial meniscectomy, 2 patients (1 %) had a complete meniscectomy, and 2 patients (1 %) had the meniscus sutured.

1.3. Study III

The patient material of this study consisted of 100 consecutive ACL reconstructions with a hamstring graft performed at the Tampere University Hospital between December 1995 and January 2001, subject to following inclusion criteria: (1) primary ACL surgery, (2) closed growth plates, (3) absence of ligament injury to the contralateral knee. Of these, 76 patients (76 %) (49 men and 27 women) were able to attend the follow-up examination.

The mean age of the patients was 34 years (range, 16 to 64) at the time of the operation. All patients had minimum follow-up of 33 months, and the mean follow-up was 57 months. Mean time between injury and operation was 2 years 4 months (SD 4.8 years).

As an additional injury, 32 patients (42 %) had a meniscal rupture at the time of the ACL surgery. 17 patients (22 %) had a medial meniscal rupture, of which 13 were partially resected and 4 were sutured. Twelve patients (16 %) had a single lateral meniscal tear, and all these were partially resected. In addition 3 patients (4 %) had ruptures in both menisci, 2 of these were partially resected and one patient had his medial meniscus sutured and lateral meniscus partially resected.

During the follow-up period, three patients had re-reconstructions of the ACL; two of them because of a high-energy trauma causing a reinjury. In addition, 3 patients reported having had a reinjury to their operated knee during the follow-up time. These knees were unstable but had not yet been re-reconstructed. One patient had a contralateral ACL injury verified by examination. These 7 patients were excluded from follow-up analysis. During the follow-up time, 7 patients had meniscal surgery and 2 had a screw removal; they were included in the analysis.

1.4. Study IV

The study IV was carried out at the Hatanpää Hospital, Tampere, Finland between March 2003 and May 2005. The 77 patients, who met the inclusion criteria (i.e. primary ACL reconstruction, closed growth plates, and absence of ligament injury to the contralateral knee), were randomized into three different groups of ACL reconstruction with hamstring tendons: double-bundle with bioabsorbable screw fixation (DB-group) (n=25), single-bundle with bioabsorbable screw fixation (SBB-group) (n=27), and single-bundle with metal screw fixation (SBM-group) (n=25). Twelve patients had a partial meniscectomy in each group at the time of the reconstruction, and two had a meniscal fixation in the DB- and SBB-groups, and 3 in the SBM-group.

Of these patients, 73 (95 %) (23 in DB-group, 26 in SBB-group, and 24 in SBM-group) were available at the minimum of two-year follow-up (range, 24 to 35 months). However, seven of these patients (five in SBB-group, one in SBM-group, and one in DB-group) had had a reinjury-induced graft failure during the follow-up (resulting in revision ACL surgery) and they were excluded from the study. Furthermore, three patients in the SBM-group

had an ACL reconstruction of the contralateral knee during the follow-up, and they were excluded from the study. Thus, 63 patients were available for the statistical analysis of the two-year results (22 in DB-group, 21 in SBB-group, and 20 in SBM-group).

1.5. Study V

This study was carried out at the Hatanpää Hospital and the University Hospital, Tampere, Finland between February 2003 and August 2005. The 62 patients, who met the inclusion criteria (i.e. primary ACL reconstruction, closed growth plates, and absence of ligament injury to the contralateral knee), were randomized with closed envelopes into two different groups of ACL single-bundle reconstruction with quadruple hamstring tendons: bioabsorbable screw fixation (B-group) (n=31), and metal screw fixation (M-group) (n=31). All ACL reconstructions were done by three experienced orthopaedic surgeons. The majority of the patients in this study are the same as in study IV.

Of these patients, 55 (89 %) (29 in B-group, and 26 in M-group) were available at the minimum of two-year follow-up (range, 24 to 36 months). However, six of these patients (five in B-group, one in M-group) had a graft failure because of a new knee injury, which led to a revision ACL surgery, and they were excluded from the study. Furthermore, three patients in the M-group had an ACL-reconstruction of the contralateral knee during the follow-up, and they were also excluded from the study. One patient was unable to undergo the MRI examination because of an anxiety attack, and other three patients declined the MRI. These patients were also excluded from analysis, thus 42 patients were available for the statistical analysis (20 in B-group, and 22 in M-group). The mean age of the patients (41 men, 21 women) was 32 years (SD 9) at the time of the operation. There was no difference regarding the

delay between the injury and operation, operative findings, follow-up time, age, height, weight and gender between the groups. In the B-group, 12/31 patients (39 %) had a partial meniscal resection, and 2/31 patients (6 %) had a meniscal repair. In the M-group, 16/31 patients (52 %) had a partial meniscal resection, and 3/31 patients (10 %) had a meniscal repair.

2. Surgical techniques

2.1. Single-bundle technique

A single-incision endoscopic technique described by Pinczewski et al. (2002) was used with anteromedial and anterolateral arthroscopy portals. First the femoral tunnel was drilled through the anteromedial portal with free-hand technique without a guide. Then the tibial tunnel drilling was done with a tibial guide. The femoral tunnel was placed in the posterior part of the intercondylar notch, at approximately 11 o'clock in the right knee and at approximately 1 o'clock in the left knee. The tibial tunnel was made to the anatomical position of the ACL insertion. Quadruple semitendinosus and gracilis graft was used. The graft was inserted retrograde via the tibial tunnel into the femoral tunnel and then fixed with metallic interference screws (Timoni Oy, Espoo, Finland) or with bioabsorbable screws (Hexalon, Inion Co, Tampere, Finland) to the femoral and tibial sites. Tunnel size equaled the cross-sectional size of the graft. In the study II, the femoral screw was placed outside-in, and an Intrafix device was used as tibial fixation for some patients. The patients in study IV, when using the single-bundle technique, and the patients in study V were operated using the same technique, but the femoral

tunnel was created at 10 o'clock position in the right knee, and at 2 o'clock position in the left knee.

2.2. Double-bundle technique

The double-bundle technique described by Järvelä (2007) was used in this study. The AM tunnel was drilled first through the standard anteromedial portal with a free-hand technique. The AM femoral tunnel was placed as posterior as possible, without breaking the posterior wall of the femoral condyle, in the posterior part of the intercondylar notch, at approximately 10 o'clock in the right knee and at approximately 14 o'clock in the left knee. The optimal placement of the tunnel was marked with a 30 degree awl. Then a guide wire was placed to the marked optimal position and drilled through the femoral condyle at 120 degrees of knee flexion. The diameter of the AM femoral tunnel was typically 7 mm, and the depth of the tunnel was 30 mm.

The PL tunnel was drilled through an additional anteromedial tunnel, which was placed about 1 cm medially from the standard anteromedial portal. The flexion angle of the knee was 90 degrees when creating the PL femoral tunnel. The diameter of the PL femoral tunnel was typically 6 mm, and the depth of the tunnel was 30 mm. The wall between these two tunnels (AM and PL) in the femoral side was at least 1-2 mm. A bony notchplasty was not performed, unless there were osteophytes in the intercondylar space.

The diameter of the doubled semitendinosus autograft was approximately 7 mm, and that of doubled gracilis autograft approximately 6 mm. Tibial tunnel drillings were done using a tibial guide with the angle set approximately to 55 degrees. The starting point of the AM tibial tunnel was the same as in the standard ACL single bundle reconstruction technique. Then the

PL tibial guide wire was placed on the PL aspect of the ACL tibial footprint. An osseous bridge of approximately 1 to 2 cm remained on the tibial cortex between these two tunnels. The diameter of the AM tibial tunnel was typically 7 mm, and that of the PL tunnel 6 mm.

The grafts were inserted retrograde via the tibial tunnels into the femoral tunnels, and then fixed with bioabsorbable screws (Hexalon, Inion Co, Tampere, Finland) proximally (inside-out) and distally (outside-in). The knee angles during the fixation of each bundle were the same as described above for drilling the femoral tunnels.

On the tibial side, the PL bundle was tensioned and fixed first the knee in full extension, followed by the AM bundle at 30 degrees of knee flexion. The bioabsorbable screws were inserted as close to the joint line as possible. An additional fixation was made with the non-absorbable sutures coming from each graft to tie them together over the cortical bone bridge between the tibial tunnels.

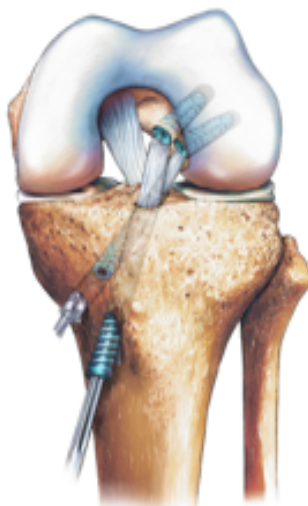


Figure 3. *The double-bundle ACL reconstruction technique with two separate tibial and femoral tunnels. (Reprinted from Knee Surg, Sports Traumatol, Arthrosc, Vol 15, Järvelä T, Double-bundle versus single-bundle anterior cruciate ligament reconstruction: a prospective, randomize clinical study, Pages No. 500-507, Copyright (2007), with permission from Springer).*

3. Postoperative rehabilitation

The patients were allowed to put weight on their operated leg, but were protected with crutches for three to four weeks. No rehabilitation brace was used, and full range of motion of the knee was permitted. Closed-chain training of the lower extremity muscles was started as soon as the patient had sufficient leg control to carry out the exercises. Cycling was permitted with an ergometer 4 weeks after the operation, running 3 months, and pivoting sports 6 months postoperatively, provided that the patient had regained full functional stability. If meniscal repair was performed at the same operation, the range of motion of the knee was allowed 0–90 degrees for the first 6 weeks. Otherwise, the rehabilitation was carried through as described above.

4. Follow-up evaluation

4.1. Subjective evaluation

Subjective-functional evaluation of the knee consisted of the Lysholm score (scale: 0 to 100) (Lysholm & Gillquist 1982) and 2000 International Knee Documentation Committee functional knee score (IKDC scale: 0 to 10 rating the subjective function of the knee). If there were no limitations in daily activities (which might include sports), the IKDC score would be 10, and 0, if the patient was unable to perform his daily activities. Patients' activity level was assessed before surgery and at the follow-up by the Tegner activity score (scale: 0 to 10) (Tegner & Lysholm 1985).

4.2. Clinical and functional evaluation

The clinical follow-up in the studies I, III, IV and V, as well as the radiographic evaluation for the graft placement in study II (while blinded to the clinical results) was done by one examiner (ASM). She had not operated on any of the patients. The patients in study II were clinically evaluated by an experienced orthopaedic surgeon.

Clinical testing included the use of the above noted standard ligament evaluation form of the International Knee Documentation Committee (2000 IKDC) (Hefti et al. 1993). In the ‘one-leg-hop’-test, the best length of two attempts was recorded and a side-to-side ratio was used (Tegner et al. 1986). The patients also performed a ‘knee-walking-test’ (the patient moves forward on his/her knees with the upper body in an erect posture the knees thus supporting the entire body weight). The ability to do this knee-walking-test was graded as normal, unpleasant (nearly normal), difficult (abnormal) or impossible (severely abnormal) (Kartus et al. 1997).

4.3. Range of motion of the knee

The range of motion of the knee was evaluated patient supine on an examination bed using a goniometer. The interlimb difference was recorded to the final evaluation of the IKDC. If the lack of knee extension was less than 3 degrees, and the lack of knee flexion less than 5 degrees compared to the other side, the range of knee motion was considered as “normal”. If the lack of knee extension was 3 to 5 degrees, or the lack of flexion six to fifteen degrees, the range of motion was considered “nearly normal”. Six to ten degrees lack of extension or 16 to 25 degrees lack of flexion was considered “abnormal”, and greater than these flexion-extension deficits were considered “severely abnormal”.

4.4. Arthrometric measurement of knee laxity

The stability measurement was done at 30 degrees of knee flexion with the KT-1000 arthrometer (MEDmetric Corporation, San Diego, CA) using a force of 134 N as described earlier (Daniel et al. 1985). The laxity was measured twice in the injured and uninjured knees and the average was recorded. The side-to-side difference of the anterior displacement was then used for the analysis. The test result was graded as normal (0 to 2 mm laxity), nearly normal (3 to 5 mm laxity), abnormal (6 to 10 mm laxity), or severely abnormal (>10 mm laxity).

4.5. Isokinetic strength testing

Prior to isokinetic muscle strength testing each subject was given a 5 min warm-up period by aerobic ergometer cycling. The subject was then fixed to the testing apparatus (Dynacom, Oy Diter-Elektroniikka Ab, Turku, Finland) with a seat belt and additional straps around the pelvis, the thigh, and malleoli. The axis of the knee was placed in line with the axis of rotation of the dynamometer. Before testing, the patient was instructed to perform a sufficient number of submaximal repetitions of knee extension and flexion in order to become familiar with the system.

The range of movement during extension and flexion was 90 degrees (approximately between 5 and 95 degrees of flexion). The quadriceps and hamstring torques were measured first at a low speed of 60 degrees/sec and after a few minutes rest at 180 degrees/sec. Each subject produced, under verbal encouragement, five maximal voluntary repetitions of alternating knee extension and flexion. The maximal peak torque was used for calculations. The non-operated limb was tested first.

The relative muscle strengths were used for the strength analysis, i.e. for each patient the muscle torque difference

between the limbs was calculated as a percentage (strength of the ACL-reconstructed knee minus strength of the contralateral knee/strength of the contralateral knee \times 100%), a minus percent thus indicating a strength deficit, and a plus percent a strength excess in the operated limb.



Figure 4. *The patient strapped to the muscle strength testing apparatus. Five maximal repetitive knee flexion-extension movements were performed.*

4.6. Radiographic evaluation for osteoarthritis

The follow-up knee radiographs (AP and lateral views) were analyzed by an experienced radiologist according to the IKDC evaluation criteria. Grade A denotes a normal knee. Grade B (mild) is defined as sclerosis of the tibial plateau, very limited flattening of the medial femoral condyle, and virtually no loss of joint space on any of the radiographs. Grade C (moderate) represents less than 50% loss of joint space; while Grade D (severe) is defined as greater than 50% loss of joint space.

4.7. Graft placement measurements

The evaluation system of the tunnel placements in ACL reconstruction has been described previously (Järvelä et al. 2001). The principles, to which the evaluation system is based, have been recommended by the ESSKA (Amis et al. 1994). The measurements were done using postoperative radiographs. Briefly, tunnel width was first measured and the tunnel center, at the level of entry into the joint, was marked as a point to describe the graft location. The femoral tunnel placement was measured from the posterior surface of the femoral condyle along the Blumensaat's line and compared to the entire length of the femoral condyle in the lateral radiograph (Figure 5). The tunnel position was expressed as a percentage from posterior-to-anterior.

For measuring the tibial tunnel placement, the distance from the anterior corner of the tibial plateau to the center of the tibial tunnel was measured and compared to the entire length of the tibial plateau in the lateral radiograph (Figure 6).

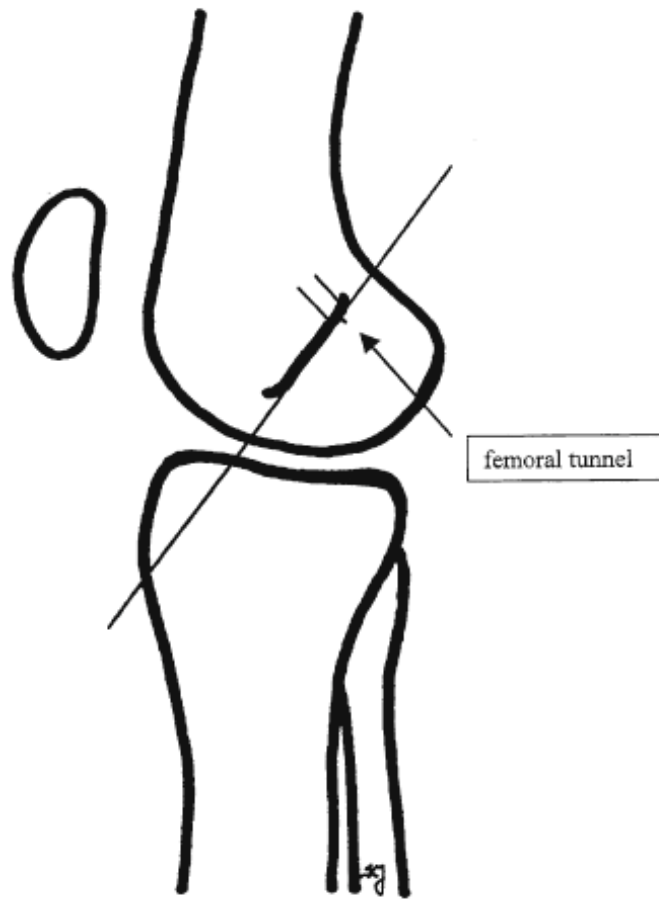


Figure 5. Measurement of the femoral graft placement. (Reprinted from *The Knee*, Vol 8, Järvelä T et al, Graft placement after the anterior cruciate ligament reconstruction: a new method to evaluate the femoral and tibial placements of the graft, Pages No. 219-227, Copyright (2001), with permission from Elsevier).

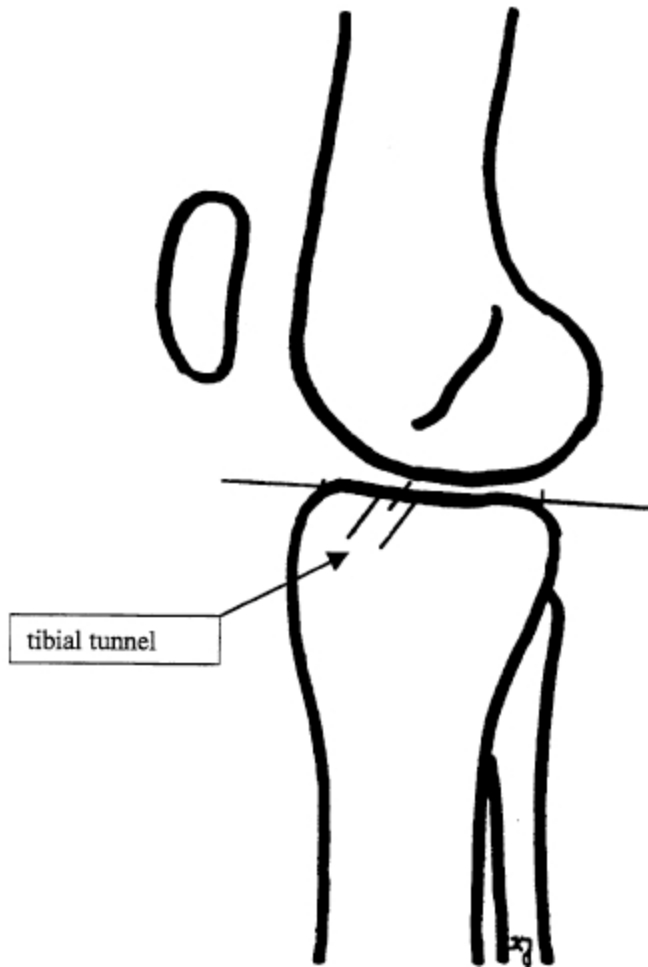


Figure 6. Measurement of the tibial graft placement. (Reprinted from *The Knee*, Vol 8, Järvelä T et al, Graft placement after the anterior cruciate ligament reconstruction: a new method to evaluate the femoral and tibial placements of the graft, Pages No. 219-227, Copyright (2001), with permission from Elsevier).

4.8. MRI evaluation

The MRI evaluation was done to study the degradation of the biodegradable interference screw, and to evaluate the anteroposterior and mediolateral diameter of the femoral and tibial tunnels 2 cm above the articular surface (mm). Also, the presence of fluid in the femoral and tibial tunnels of the patients with bioabsorbable screws was evaluated.

The MRI was performed with a 1.5-T imager Signa Exite HD (General Electric, Milwaukee, WI) using eight channel receiver/transmitter extremity coil. The oblique coronal and sagittal images were placed parallel to the longitudinal axis of the ACL graft in the joint using a sagittal and coronal scout view. The diameter of the drill used to create the tunnels at the time of surgery was used as the original tunnel width. The original width was subtracted from the tunnel width determined by MRI at the final follow-up and the difference expressed as a percentage of the original width.

Intraobserver agreement was evaluated. 20 patients were chosen randomly and tunnel diameters were measured. Time interval between the first and the second evaluation was 2 months.

5. Statistical methods

The results of the variables are reported as mean and standard deviation (SD). The significance level was set to $p < 0.05$.

The non-parametric Mann-Whitney U-test was used when testing the differences in the continuous variables between two independent groups, and the non-parametric Kruskal-Wallis test when testing the differences between more than two groups.

Thus, the Mann-Whitney U-test was used when comparing the differences of the means between the group with meniscal resection and the group without meniscal resection (I), to compare the differences of the mean knee extension and flexion torque deficits, the Tegner score, and the results of the 'one-leg-hop'-test between the BTB and Hamstring groups (III). This test was also used to compare the differences between the B- and M-groups (V). The Kruskal-Wallis test was used to test the differences in sumscore, tibial or femoral graft placement in different IKDC rating groups, or with respect to Lachman or pivot-shift test (II), and torque deficits versus stability (III). This test was also used to compare the side-to-side differences to tunnel diameter (V).

The Spearman rank correlation was used to compare the Lysholm scores or the knee stability to the follow-up time (I), the sumscore and its components to the Lysholm score (II), and to compare the Lysholm scores to the knee extension and flexion torque deficits, and the HQ ratios to the follow-up time (III).

The one-way ANOVA and paired-samples t-test were used to calculate between differences of means in study IV. The chi-square test was used to compare the differences of the frequencies in studies III and IV.

Results

1. Evaluation of muscle strength (study I)

Overall, the torque deficits were rather small (10 % or less), slightly greater at the lower than higher speed of movement, and not significantly different between the BTB and Hamstring groups (Table 2). The mean Lysholm score of the patients was 89 (SD 8) in the BTB group, and 89 (SD 13) in the Hamstring group. The mean Tegner activity score at the follow-up was 5 (SD 2) in the BTB group, and 6 (SD 2) in the Hamstring group ($p=0.3$). In the BTB group, 69 % of the patients were considered as normal or nearly normal according to the IKDC rating score, and 71 % in the Hamstring group ($p=0.9$).

TABLE 2.

Relative isokinetic quadriceps and hamstrings peak torques compared to the contralateral limb (ACL-reconstructed knee minus contralateral knee/contralateral knee x 100 %) of patients 6 years after an ACL reconstruction using a BTB or a hamstring autograft. Mean (SD) torques in percentages, a negative value indicating a deficit compared to the torque of the contralateral limb. The HQ-ratios of the ACL-reconstructed knees are also presented.

	Angular velocity	BTB graft (n=16)	Hamstring graft (n=28)	p value
Quadriceps peak torque (%)	60 °/sec 180 °/sec	-10 (11) -5 (12)	-7 (15) -2 (15)	p=0.3 p=0.8
Hamstrings peak torque (%)	60 °/sec 180 °/sec	-1 (16) 1 (12)	-3 (10) 0 (10)	p=0.8 p=0.5
HQ-ratio	60 °/sec 180 °/sec	59 (8) 64 (13)	58 (10) 64 (10)	p=1.0 p=0.8

1.1. Effect of length of follow-up

When analyzing the data of all patients (n=44), the knee extension torque deficit at 180 °/sec had a significant negative correlation to the length of the follow-up, as well as the knee flexion torque deficit at 60 °/sec ($r = - .37$, $p=0.01$ for the former and $r = - .36$, $p=0.02$ for the latter) indicating that the deficits became smaller by time.

In the BTB group, the HQ-ratio at 180 °/sec correlated negatively with the length of the follow-up ($r = - .74$, $p=0.001$) so that the HQ ratio decreased over time, at 60 °/sec the correlation

was quite strong, but not quite significant ($r = -.44$, $p = 0.09$). The HQ ratios of the Hamstring group did not correlate with the length of the follow-up ($r = -.22$, $p = 0.3$ at $60^\circ/\text{sec}$, and $r = -.02$, $p = 0.9$ at $180^\circ/\text{sec}$)

1.2. Association with the clinical outcome

The subjective Lysholm knee score correlated negatively with the knee extension torque deficit at $60^\circ/\text{sec}$ ($r = -.35$, $p = 0.02$), and with the knee flexion torque deficit at $60^\circ/\text{sec}$ ($r = -.30$, $p = 0.045$) indicating that the Lysholm score was better when the strength difference between the operated and the non-operated limb was smaller.

The knees that were considered stable when evaluated with the KT-1000 arthrometer had significantly less flexion torque deficit at $180^\circ/\text{sec}$ compared to the knees with nearly normal or abnormal stability ($p = 0.047$).

2. Graft placement and clinical outcome (study II)

The mean Lysholm score of the ACL-reconstructed knees (scale 0–100) was 92 (SD 10). There was a correlation between the femoral graft position and the Lysholm score ($r = -.20$, $p=0.04$) at the 2-year follow-up: the Lysholm score was higher in knees with a more posterior femoral graft placement than in those with a more anterior placement. The sumscore was significantly smaller, when the Lachman test was normal ($p=0.002$) and the pivot shift test was normal ($p=0.01$) (Table 3).

The IKDC scores are presented in Table 4. There was no statistical difference between the sumscore, or the femoral or tibial graft placements in different IKDC rating groups at the 2-year follow-up. When the tibial graft placement was between 32 and 37 %, 23 of 25 patients (92 %) were rated normal or nearly normal according to the IKDC rating. The same figures were 26 of 27 patients (96 %) with the femoral graft placement between 25 and 29 %, and 25 of 28 patients (89 %) with the sumscore between 61 and 66.

TABLE 3.

The graft placement with regard to the Lachman and pivot shift test at the 2-year follow-up. Mean (SD). No patient was evaluated as severely abnormal. NS equals no significant correlation.

	Normal	Nearly normal	Abnormal	Significance
Lachman test	(n=68)	(n=34)	(n = 1)	
Sumscore	65 (7)	71 (6)	70	p=0.002
Femoral graft placement	29 (6)	30 (6)	37	NS
Tibial graft placement	37 (6)	41 (7)	33	p=0.04
Pivot shift test	(n=84)	(n=18)	(n=1)	
Sumscore	66 (7)	72 (7)	70	p=0.01
Femoral graft placement	29 (6)	31 (5)	37	NS
Tibial graft placement	38 (7)	41 (7)	33	NS

TABLE 4.

The mean graft placements in the IKDC groups at the 2-year follow-up. NS equals no significant correlation.

	IKDC rating				Significance
	Normal (n=23)	Nearly normal (n=62)	Abnormal (n=17)	Severely abnormal (n=1)	
Sumscore	65	67	71	69	NS
Femoral graft placement	28	29	30	33	NS
Tibial graft placement	37	38	41	36	NS

3. Hamstring autograft with interference screw fixation (study III)

According to the IKDC score, 22 patients (32 %) were normal, 32 patients (46 %) nearly normal, 13 patients (19 %) abnormal, and 2 patients (3 %) severely abnormal. The mean Tegner score was 5 (SD 2) at the follow-up. The mean patient functional scoring according to IKDC was 10 (SD 1) prior to injury, and 8 (SD 2) at the follow-up. Full stability (side-to-side difference 0 to 2 mm) was achieved in 46 patients (67 %). The mean Lysholm score of all patients was 85 (SD 16) at the follow-up.

In radiographic evaluation, medial tibiofemoral joint was regarded as normal in 46/66 patients (70 %) (Table 5). The knee-walking-test was normal in 59 patients (86 %), nearly normal in 6 patients (9 %), abnormal in 4 patients (5 %), and severely abnormal in one patient (1 %).

TABLE 5.

The Lysholm score and side-to-side difference (mm) in the anterior-posterior stability using KT-1000-arthrometer (force of 134 N) with respect to meniscal resection. Mean (SD). Osteoarthritic changes (in medial or lateral tibiofemoral joint) with respect to meniscal resection and the stability of the knee. No severe osteoarthritic changes were found. There were more often mild-to-moderate osteoarthritic changes in the meniscectomized knees than knees without meniscal resection (46 % vs. 20 %) ($p=0.03$).

	Meniscal resection		Significance
	Done (n=27)	Not done (n=42)	
Lysholm score (0 to 100)	82 (14)	87 (17)	$p=0.04$
Side-to-side difference (mm)	1.9 (3.1)	1.7 (2.6)	NS
Osteoarthritic changes			
None (n=46)	14 (54 %)	32 (80 %)	
Mild (n=11)	8 (31 %)	3 (7.5 %)	
Moderate (n=9)	4 (15 %)	5 (12.5 %)	$p=0.03$

4. Double-bundle technique compared to single-bundle technique (study IV)

The KT-1000 arthrometer measurements preoperatively and at the follow-ups, and the percentage of patients with no pivot-shift at the 1-year and 2-year follow-ups are presented in Figures 7 and 8, respectively. The rotational stability was better in the patients with the double-bundle technique. There were 7 reinjury-induced graft failures during the follow-up; one in the DB-group, 5 in the SBB-group and 1 in the SBM-group.

There were no statistically significant differences between the groups according to the IKDC score, IKDC functional score, and Lysholm score preoperatively, at the 1-year or 2-year follow-ups. The Lysholm scores are presented in Figure 9. The mean IKDC functional score preoperatively was 5 (SD 2) in the DB and SBM groups, and 6 (SD 2) in the SBB group. At the 1-year follow-up it was 8 (SD 1) in all groups, and at the 2-year follow-up 9 (1) in the DB and SBB groups, and 9 (2) in the SBM group (NS). At the 2-year follow-up, the IKDC score was graded as normal or nearly normal with 21/22 patients (95 %) in the DB group, 18/21 (86 %) in the SBB-group, and 19/20 patients (95 %) in the SBM-group (NS).

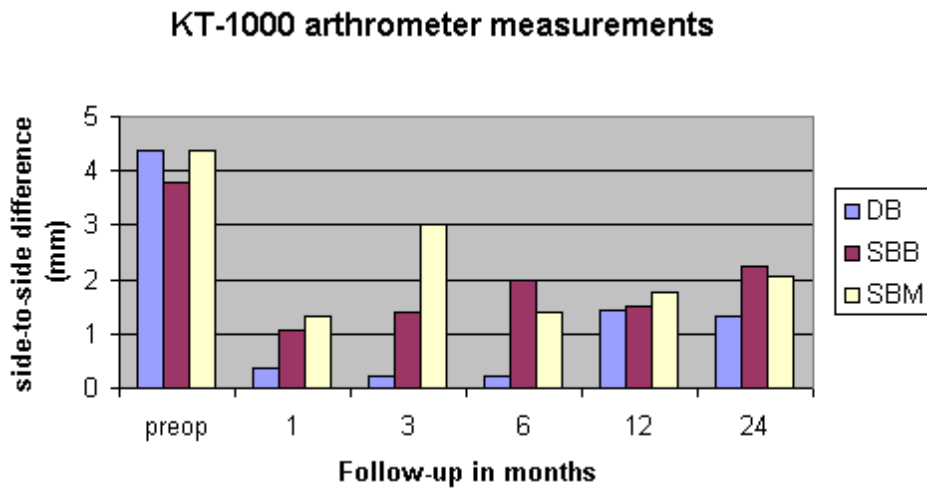


Figure 7. The KT-1000 arthrometer measurements using a force of 134 N. The group differences were not statistically significant. However, the anterior stability was significantly better in every group at the 1-year and 2-year follow-ups than preoperatively ($p < 0.001$).

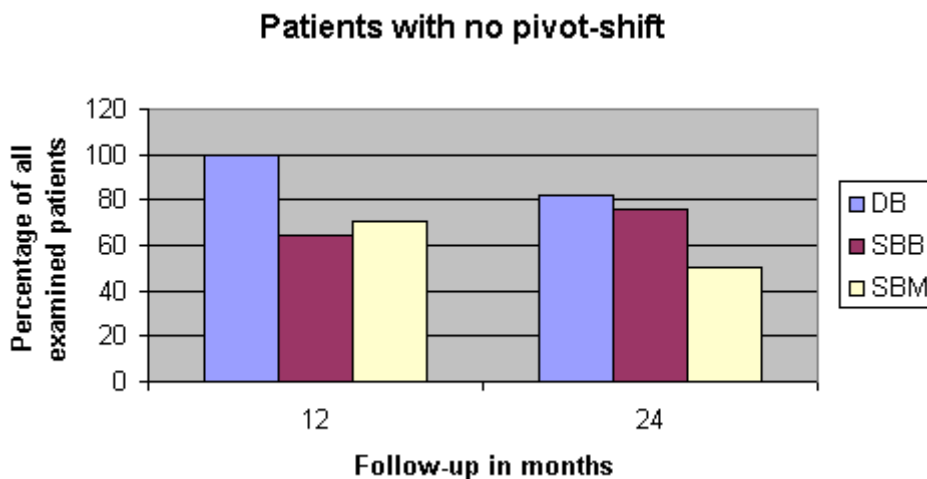


Figure 8. The percentage of the patients with no pivot-shift of all patients examined at each follow-up (1-year and 2-years). Preoperatively all patients had a positive pivot shift test. Rotational stability was significantly better in patients with the double-bundle technique than in those with the single-bundle techniques at the 1-

year follow-up ($p=0.005$). At the 2-year follow-up the DB group had a significantly better result than the SBM group ($p<0.05$), the difference to the SBB-group was not significant. However, if the seven graft failures (with a positive pivot shift test) (5 in SBB-group) were included into the statistical analysis, the DB-group would have a significantly better result than the SBB-group ($p<0.05$).

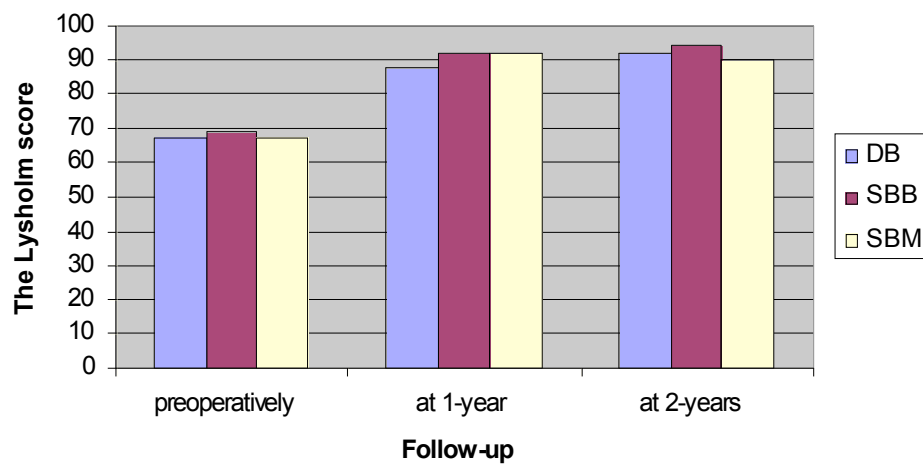


Figure 9. The Lysholm scores preoperatively, at 1-year and 2-years follow-up. The group differences were not statistically significant at any time point.

5. Magnetic resonance imaging of bioabsorbable compared to metal screw fixation (study V)

At surgery, the mean diameter of the femoral tunnel was 6.9 mm in the bioabsorbable screw group (B-group), and 7.4 mm in the metal screw group (M-group). The mean tibial tunnel diameter was 7.4 mm in the B-group, and 7.8 in the M-group. There was tunnel widening in both groups. However, at the two-year follow-up MRI, the femoral tunnel diameter was significantly wider in the B-group compared to the M-group in the AP direction ($p=0.01$) as shown in Figure 10. The tibial tunnels showed no intergroup difference (Figure 11).

There were five revision cases in the B-group, and two patients had a side-to-side difference of 6 mm evaluated with the KT-1000 arthrometer, so the graft failure rate was 7/31 patients (23 %). In the M-group, one revision was done during the follow-up, and one patient had 6 mm side-to-side difference evaluated with the KT-1000 arthrometer. Thus, in the M-group, the graft failure rate was 2/31 patients (6 %).

After excluding the graft failures, there was no significant difference between the groups in the IKDC evaluation, or in the Lysholm score. The follow-up AP tibial tunnel diameter was smaller with normal knee laxity compared to nearly normal or abnormal knee laxity ($p=0.02$). (Table 6)

The bioabsorbable screw was still partly visible in 14/20 patients (70 %) in the femur, and in 17/20 patients (85 %) in tibia (Figure 6). The bioabsorbable screw was not visible in six of twenty femurs and three of twenty tibias.

Agreement between the first and the second evaluation was good. Repeated measurements showed similar results in 59% of cases and in 41% of cases they differed from each other between -1-+1 millimetres.

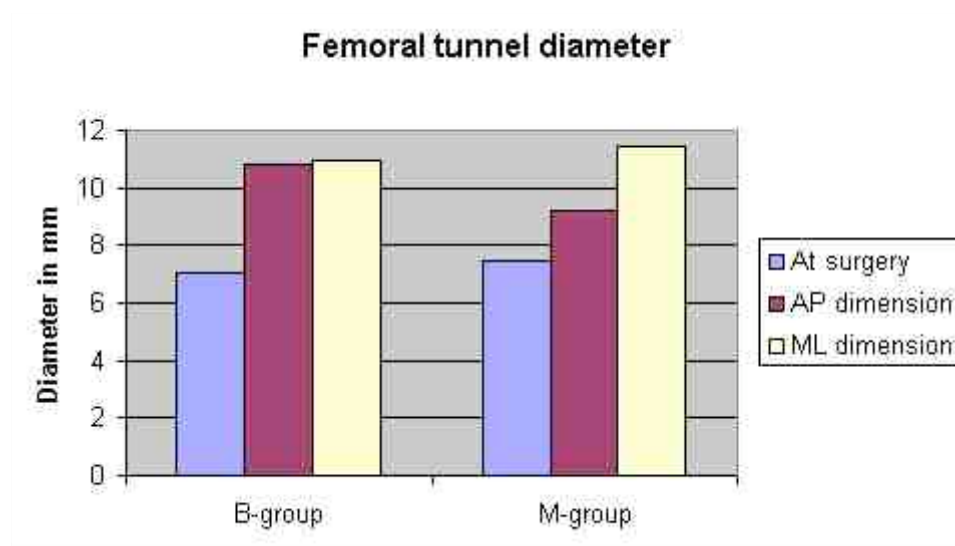


Figure 10. The mean femoral tunnel diameters (mm). At the two-year follow-up, evaluated by the MRI, the tunnel diameter in the AP dimension was significantly larger in the B-group compared to the M-group ($p=0.01$).

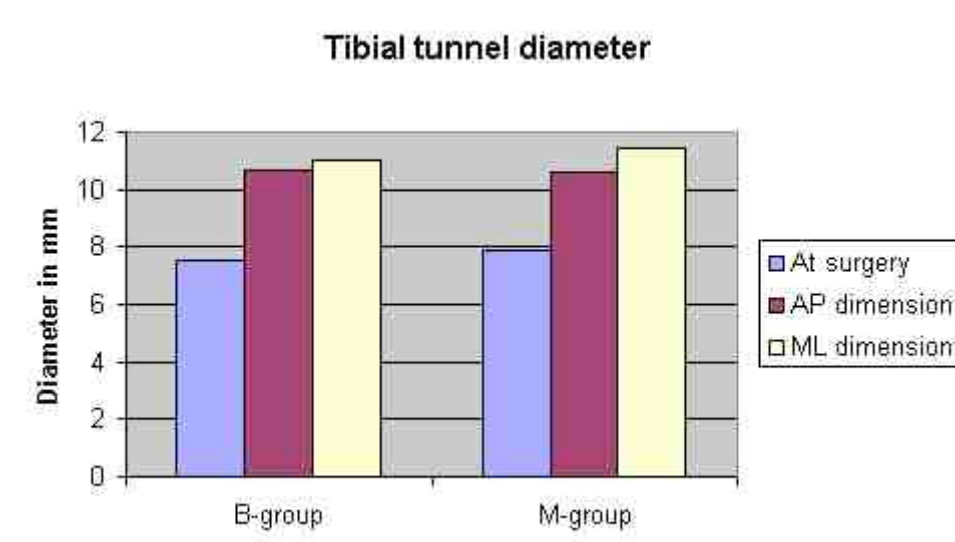


Figure 11. The mean tibial tunnel diameters (mm). There were no statistically significant differences in the tunnel diameters between the groups.

TABLE 6.

The mean tunnel dimensions in the MRI with respect to the laxity evaluated with the KT-1000 arthrometer. Mean (SD).

		Side-to-side difference			Significance
		0-2 mm (n=25)	3-5 mm (n=14)	>5 mm (n=3)	
Femoral tunnel diameter	AP dimension	9.7 (1.8)	10.2 (2.0)	11.7 (4.7)	NS
	ML dimension	11.0 (1.6)	11.4 (1.4)	11.0 (0)	NS
Tibial tunnel diameter	AP dimension	10.2 (1.5)	11.1 (1.2)	12.3 (1.5)	p=0.02
	ML dimension	10.5 (1.8)	11.6 (2.1)	12.0 (2.6)	NS

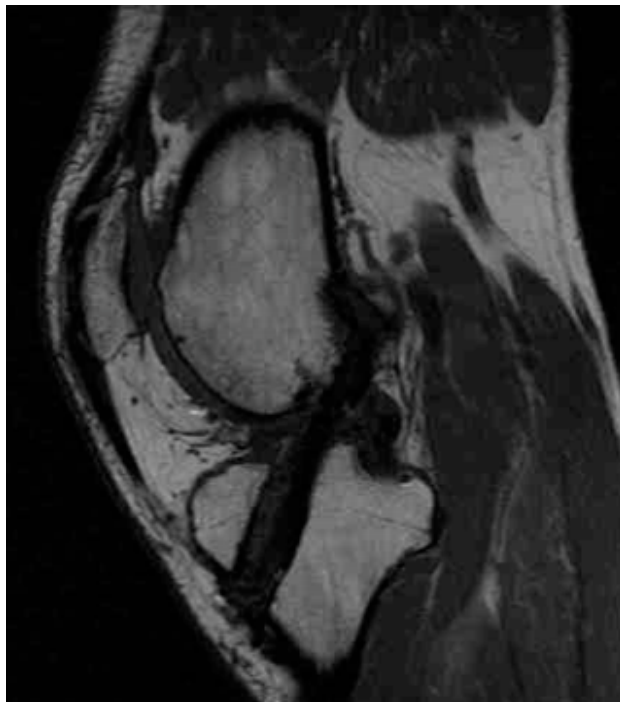


Figure 12. *Two-year MRI of a patient operated using bioabsorbable screws. The graft is intact and there is no sign of the bioabsorbable screws. Tunnel enlargement can be seen in tibia.*

Discussion

One of the main objectives of this thesis was to examine factors which contribute to the clinical outcome after the anterior cruciate ligament reconstruction. Although much attention is nowadays paid to the different reconstruction techniques this thesis showed that the condition of the knee at surgery, the operative technique (including the graft placement), and the rehabilitation result are all important factors for the outcome of the patient.

With the previously used slow rehabilitation, which generally included the use of a hinged brace or cast 4 to 6 weeks postoperatively, considerable strength deficits have been reported. Natri et al. (1996) showed 5 to 20 % deficits after 4 years. However, the current surgical techniques, immediate mobilization and full weight-bearing allow earlier and much more intense rehabilitation. Recent reports show clear strength deficit postoperatively, which is related to graft harvest. Harvesting a BTB autograft results in quadriceps weakening (Kobayashi et al. 2004), and the use of hamstring tendons in knee flexion strength deficit, respectively (Eriksson et al. 2001, Yasuda et al. 1995). These short-term studies have, however, shown considerable recovery in the affected muscles during the first two postoperative years.

Therefore, it was somewhat surprising to note that after 6 years, patients still had strength deficits compared to the contralateral limb. Quadriceps and hamstring strengths deficits existed regardless of the graft type. The strength loss appeared to

become smaller over time, and especially in the BTB group quadriceps strengthening superior to hamstring strengthening seemed to occur. However, this conclusion cannot be confirmed by this cross-sectional study.

Not so surprisingly, muscle atrophy correlated with the clinical outcome in the study I. When the quadriceps and hamstring strengths of the operated limb were close to those of the contralateral limb, the patients had less symptoms (higher Lysholm score). Also, better stability evaluated with the KT-1000 arthrometer was associated with less hamstring torque deficit. This is in accordance with the findings of Li et al. (1996), who showed that increasing the hamstring strength helped to stabilize the knee, and a high HQ ratio was associated with good function of the knee. On the other hand, the activity level of patients with a stable knee may be higher compared to those with an unstable knee. Overall, these results support the use of intense rehabilitation after ACL reconstruction.

There is a debate of the optimal timing of surgery. The incidence of meniscal tears increases over time in ACL-deficient knees (Papastergiou et al. 2007), and it has been shown that a meniscal injury increases the rate of osteoarthritis (Aglietti et al. 1997, Beynnon et al. 2005a, Cohen et al. 2007, Jomha et al. 1999). ACL reconstruction decreases the risk of secondary meniscal tears but may not decrease the likelihood of suffering posttraumatic osteoarthritis (Lohmander & Roos 1994, Lohmander et al. 2007).

The time between injury and reconstruction was often relatively long, but it did not correlate with the final outcome (study III). The condition of the knee at the time of surgery seems to be more important than the timing of surgery (Beynnon et al. 2005a). Meniscectomy was associated with lower Lysholm scores and more osteoarthritic changes. This is in accordance with previous studies (Aglietti et al. 1997, Jomha et al. 1999).

The position of the ACL graft has a direct effect on knee biomechanics and, ultimately, on clinical outcome (Beynon et al. 2005b). A non-isometrically placed graft is likely to stretch and cause increase in laxity (O'Meara et al. 1992). The graft placement has to be considered 3-dimensionally. Good et al. (1994) showed that the closer to the center of the femoral insertion in the sagittal direction (lateral view) the graft is placed, the better the AP stability. Later on, Loh et al. (2003) showed that a graft placed at 10 o'clock (frontal view) was better able to resist rotation and anterior tibial torque compared to the 11 o'clock position. In the tibia, Howell and Clark (1992) showed that a too anterior graft placement results in graft impingement against the intercondylar roof and Khalfayan et al. (1996) suggest placing the tunnel at least 20 % from the anterior edge of the tibia along the tibial plateau. Evaluation of both the femoral and tibial graft placements together (sumscore) in study II predicted both the AP and the rotational stability with the single-bundle technique.

The ACL as a whole is not isometric; instead the fibre bundles lengthen and shorten during the range of motion of the knee (Amis & Dawkins 1991). Both the femoral and the tibial graft placement affect the fibre length patterns, although the femoral attachment has more effect than the tibial attachment site (Amis et al. 1994). Furia et al. (1997) showed that isometric measurements of the ACL varied depending on fiber origin from the femoral attachment. They suggest that clinically intraoperatively measured elongation of up to 3 mm in reconstructed ACLs is acceptable as long as it recreates the pattern of the native ACL. An ideal graft placement (with an optimal sumscore) would lead to minimal graft length changes. This is likely to explain why the sumscore (considering both femoral and tibial attachments simultaneously) had an association with both the AP and rotational stability.

When performing the single-bundle technique, the correct positioning of both the femoral and tibial placements of the ACL graft have to be considered during surgery. The femoral tunnel should be placed as posterior as possible without breaking the condylar wall, and the tibial placement in the anterior part of the tibial insertion of the original ACL but making sure there is no impingement (minimum 20 % posterior from the anterior edge of the tibial plateau). The usual landmarks when drilling the tibial tunnel are the tibial spine and the anterior horn of the lateral meniscus.

The observations regarding the abnormal kinetics of ACL-reconstructed knees and the failure of the single-bundle techniques to restore it to normal have resulted in the advent of double-bundle techniques. In the study IV, reconstructing both bundles (AM and PL) of the ACL resulted in better rotational stability compared to the single-bundle technique and possibly protected the patients from a new trauma-induced graft failure. Rotational stability was also noted to be better with the double-bundle technique in the previously reported 1-year results of this series (Järvelä 2007), and, in the other four prospective randomized or semi-randomized studies comparing these new techniques to the single-bundle technique (Aglietti et al. 2007, Muneta et al. 2007, Yasuda et al. 2006, Yagi et al. 2007). In these five studies, the fixation and the instrumenting techniques used are very different from each other. However, they all showed better clinical results (all showed better rotational, and most of them also better AP stability) with the double-bundle technique compared to the single-bundle technique.

According to the study of Pinczewski et al. (2007) graft rupture was associated with increased instrumented anteroposterior knee laxity (> 2 mm side-to-side difference) at 2-years. In the study IV, there was no statistically significant between-groups difference in the AP stability of the knee, but there were more graft failures

with the single-bundle groups compared to the double-bundle group. The patients in the double-bundle group also had less pivot-shift at the 1-year follow-up compared to both single-bundle groups. At the 2-year follow-up the difference was significant compared to the SB-metallic interference screw group. However, by the 2-year follow-up, 5 patients in the single-bundle bioabsorbable screw group had revision surgery because of graft failure. Perhaps, as in the work of Pinczewski et al. (2007), a small increase in the AP laxity predicted the graft failure, also in the study IV of this thesis, the worse rotational stability in the single-bundle groups at the 1-year follow-up predicted later graft failure. In any case, the pivot shift test is used as an important indicator for ACL surgery.

Overall, the new double-bundle ACL reconstruction technique was proven to be sound for clinical use. However, long-term studies are needed to evaluate the possible knee joint protective effects of better rotational stability achieved with this new technique.

Since the knee kinematics after a single-bundle ACL reconstruction has been shown to be abnormal (Tashman et al. 2004), the difference in loading could contribute to the development of osteoarthritic changes. In such case, the new reconstruction technique might be able to protect the knee joint from degenerative changes. As of today there is no evidence yet to support this theory since there are no prospective randomized studies comparing the double-bundle reconstruction to single-bundle technique with a longer than 2-year follow-up.

Generally, to show differences in the prevalence or severity of osteoarthritic changes between patients who had an accompanying meniscus rupture at the time of the ACL-reconstruction and those who did not, has required 5-7 years of follow-up (Daniel et al. 1994, Jomha et al. 1999). A recent systematic Cochrane review (Linko et al. 2005) suggests a

minimum of 10-year follow-up for studies comparing surgical treatment versus conservative treatment to establish the effects on degenerative changes. Therefore, this should probably also be the minimum follow-up to evaluate these differences between reconstruction techniques as well.

The use of bioabsorbable material is appealing, because such material does not interfere with postoperative magnetic resonance imaging, and there is no need for removal, since the material turns into bone. The problem with comparing research studies about bioabsorbable screws in ACL reconstruction is that many biodegradable materials and different evaluation methods to study the outcome have been used (Lajtai et al. 2001, Laxdal et al. 2006, Siebold 2007). Some materials take more time to degrade than others. Usually, faster degrading has been associated with larger tunnel widening (Lajtai et al. 1999). Also, it seems that some bioabsorbable materials cause more tunnel widening than others. For instance Robinson et al. (2006) compared poly-L-lactic acid (PLLA) screws to poly-L-lactic acid/hydroxyapatite (PLLA-HA) screws in 24 to 36 months follow-up. They found 46 % tibial tunnel widening with the PLLA screw compared to 29 % with the PLLA-HA screw. In the study V, there were no clinically significant adverse reactions during the follow-up.

In the study V, use of bioabsorbable screws resulted in greater femoral tunnel widening compared to metal screw fixation. Also, the graft failure rate of the bioabsorbable screw group was very high (23 % vs. 6 %). Unfortunately we do not have MRI of these patients to compare their tunnel diameters to those who had good results. After excluding the graft failures, the IKDC and Lysholm scores, and the laxity testing results in the B- and M-groups were comparable.

This is in accordance with the study of Laxdal et al. (2006). They used plain radiographs and found more tunnel widening in the patients with the use of a PLLA screw compared to metal

screw fixation 2-years after ACL reconstruction. However, they found no significant difference in the clinical outcome between the groups.

Evaluation of the AP tibial tunnel diameters at the two-year follow-up MRI showed a correlation with the knee stability; the larger the tunnel, the less stability. Interestingly, this correlation was not seen in the other dimensions. It may be, that in the other dimensions, the differences in the tunnel widening were not large enough to correlate with lower stability as seen in the bioabsorbable screw group (Peyrache et al. 1996).

To our knowledge, this is the first time anyone has studied the possible association of tunnel diameter with the clinical outcome. In contrast, the association between the tunnel widening when using an STG graft was investigated by Fules et al. (2003), whose two patients had considerable tunnel widening (113 % and 165 % increase in the cross-sectional area from that at surgery) but no correlation with the clinical outcome.

In the study V, the bioabsorbable screw was still present in 70 % of patients in the femur, and in 85 % of patients in tibia. Based on the revision cases and second-look arthroscopies performed on the patients in studies IV and V, the bioabsorbable screws were already soft at 8 months and completely absorbed at 24 months. Therefore, it seems possible, that at least in some cases the follow-up MRI finding is sclerotic bone surrounding the prior screw location (Barber & Dockery 2006). This phenomenon simulates the screw and makes the evaluation of the absorption difficult. The bioabsorbable screw used in this study (Hexalon) did not cause any clinically significant adverse reactions during the two-year follow-up.

Summary and Conclusions

1. Muscle strength deficits can be found years after ACL reconstruction despite early and intense postoperative rehabilitation. However, both quadriceps and hamstring strengths seem to recover during the postoperative years, especially the quadriceps strength when using a BTB autograft. The muscle strength deficits, when compared to the contralateral limb, have an association with the clinical outcome of the patient (symptoms and stability). (Study I)
2. The graft placement (as assessed by simultaneous evaluation of the femoral and tibial graft positions) has an effect on both anteroposterior and rotational stability of the knee so that optimal graft positioning improves the stability. Also, the femoral graft placement has an association with patients' symptoms, as evaluated with the Lysholm score. (Study II)
3. The interference screws used for QSTG fixation in ACL reconstruction produce good medium-term (mean 5 years) results. An accompanying meniscus rupture at the time of the ACL reconstruction increases the occurrence of later symptoms and osteoarthritis. (Study III)
4. ACL reconstruction with the double-bundle technique improves the rotational stability of the knee better than that with the single-bundle technique. It may thus provide better

ability to resist torques produced by knee valgus and internal tibial rotation and protect from new injuries and associated graft failures. There was no intergroup difference in the anteroposterior stability. (Study IV)

5. The use of bioabsorbable screws (B-group) results in more femoral tunnel widening compared to metal screws (M-group), and more graft failures. After excluding the graft failures, the two-year clinical results of the B- and M-groups are equally good. The follow-up AP tibial tunnel diameter has an association with the knee stability. The bioabsorbable screw used in this study (Hexalon) seems not to cause clinically significant adverse reactions during two-year follow-up. (Study V)

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Anna-Stina Moisala

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