

Mattias Lidén

Long-term studies after primary and revision Anterior Cruciate
Ligament reconstruction using different types of autograft – with
special emphasis on the clinical, radiographic, histological and
ultrastructural results

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Att stå med var sitt ben
i Orsa och i Flen
är inte bara dumt och löjligt
utan även stört omöjligt

Galenskaparna

Long-term studies after primary and revision Anterior Cruciate Ligament reconstruction using different types of autograft– with special emphasis on the clinical, radiographic, histological and ultrastructural results

**Mattias Lidén
Göteborg 2008**

The aim of this study was to evaluate the long-term outcome after primary ACL reconstruction surgery using either BPTB or HT autografts and, in addition, ACL revision surgery using re-harvested patellar tendon autografts. Clinical and standard radiographic assessments were made of both the primary ACL-reconstructed knees and the patients who underwent ACL revision surgery using re-harvested patellar tendon autografts. Furthermore, in the revised knees, the patellar tendon underwent radiographic evaluations using MRI two and ten years after the index operation and histological and ultrastructural evaluations using a light and transmission electron microscope at ten years.

In 14 patients, who were examined two and ten years after the re-harvesting procedure for revision ACL surgery, the clinical results were poor and the patellar tendon at the donor site had not normalised, as seen on MRI at both two and ten years. No differences in terms of the MRI assessments were registered between the two- and ten-year assessments.

In a prospective, randomised seven-year follow-up study, 71 patients underwent primary ACL reconstruction using either BPTB or HT autografts. The objective and subjective outcomes were similar between the groups and a significant improvement compared with the pre-operative values was seen in most clinical assessments. No difference in terms of donor-site morbidity was found.

One hundred and twenty-four patients who underwent an ACL reconstruction using either BPTB or HT autografts were included in a retrospective study comparing the radiographic OA findings seven years after ACL reconstruction. No significant differences between the graft types in terms of OA findings classified according to the Ahlbäck and Fairbank rating systems were found between the study groups. Associated meniscal injuries increased the prevalence of OA.

Specimens from the patellar tendon of 12 patients were obtained using an ultrasonography-guided biopsy procedure ten years after re-harvesting the central third of the patellar tendon at revision ACL surgery. The histological evaluation using the light microscope revealed a deterioration in fibre structure with increased cellularity and increased vascularity in both the central and peripheral parts of the index patellar tendon specimens compared with normal control tendon. The ultrastructural evaluation using the electron microscope revealed pathological cell morphology and a change in fibril size class distribution compared with the normal control tendon.

Keywords:

anterior cruciate ligament, surgery, radiology, biopsy, osteoarthritis, histology, ultrastructure

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This thesis is based on the following papers, which will be referred to in the text by their Roman numbers (I-IV).

I. The course of the patellar tendon after reharvesting its central third for ACL revision surgery.

A long-term clinical and radiographic study.

Lidén M, Ejerhed L, Sernert N, Bovaller Å, Karlsson J, Kartus J.
Knee Surgery Sports Traumatology Arthroscopy 2006;14:1130-1138

II. Patellar tendon or semitendinosus tendon autografts for Anterior Cruciate Ligament reconstruction.

A prospective randomised study with a 7-year follow-up.

Lidén M, Ejerhed L, Sernert N, Laxdal G, Kartus J.
American Journal of Sports Medicine 2007;35:740-748

III. Osteoarthritic changes after Anterior Cruciate Ligament reconstruction using bone-patellar tendon-bone or hamstring tendon autografts.

A retrospective 7 year follow-up study.

Lidén M, Kartus C, Sernert N, Rostgård-Christensen L, Ejerhed L.
Accepted Arthroscopy 2008

IV. A histological and ultrastructural evaluation of the patellar tendon ten years after reharvesting its central third.

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CONTENT

Abstract	3
List of publications	4
Abbreviations	6
Introduction	7
Review of the literature	10
Aims of the study	19
Patients and demographics	20
Methods	24
Statistical methods	38
Summary of the papers	40
Strengths and limitations	51
General discussion	54
Conclusions	63
Clinical relevance	64
Final considerations and the future	65
Abstract in Swedish	67
Acknowledgements	68
Financial support	70
References	71
Papers I-IV	

ABBREVIATIONS

AB/PAS	Alcian Blue/Periodic Acid-Schiff
ACL	Anterior Cruciate Ligament
AP	Anterior Posterior
BPTB	Bone-Patellar Tendon-Bone
ECM	ExtraCellular Matrix
GAGs	GlycosAminoGlycans
HE	Hematoxylin and Eosin
HT	Hamstring Tendon
IKDC	International Knee Documentation Committee
OA	OsteoArthritis
MRI	Magnetic Resonance Imaging
PG	ProteoGlycans
RSA	Radio Stereometric Analysis
ROM	Range Of Motion
SD	Standard Deviation
ST	SemiTendinosus
ST/G	SemiTendinosus/Gracilis
TEM	Transmission Electron Microscopy
US	UltraSonography

INTRODUCTION

Rupture of the Anterior Cruciate Ligament (ACL) is one of the most frequent sports-related injuries, with an annual incidence rate of approximately one (1) injury per 3,500 persons, resulting in approximately 100,000 new ACL injuries a year in the USA.³⁹ This estimate is probably low because, every year, the annual number of ACL reconstructions is between 50,000 and 100,000 in the USA.^{18, 63, 213} Approximately 3,500 procedures are performed in Sweden each year.¹⁸⁴

Injuries to the ACL are mostly sustained by athletes and they are common among the young active population in general. Female athletes have a roughly three to nine times higher incidence of ACL injury.^{73, 147, 177} A rupture of the ACL is regarded as a serious knee ligament injury because of its pronounced risk of long-term disability. The complete natural history of the ACL-injured knee remains unclear, as there are no well-designed prospective cohort studies which describe the long-term history from adolescence to old age. However, retrospective studies commonly report that the injuries are immediately functionally disabling and they predispose to subsequent injuries, chronic instability, muscle weakness and the early onset of osteoarthritis (OA).^{18, 70} ACL reconstruction is successful in restoring knee stability and function, as described in several studies.^{18, 21, 65, 71, 242} Although the superiority of surgical treatment over the conservative alternative has yet to be scientifically proven, there are a multitude of studies in the literature focusing on the genesis, predisposing factors, treatment, rehabilitation, morphology and results after ACL injury and reconstruction. A PubMed search in January 2008 using the term “Anterior Cruciate Ligament (ACL)” produced almost 10,000 articles on the topic.

For decades, the patellar tendon was the most common autograft for ACL reconstruction. The reconstruction was performed with an open or arthroscopic technique, using the central third of the patellar tendon with bone blocks at both ends. In many reports, this technique renders good, reproducible results.^{36, 48, 53, 173, 197} In general terms, the bone-patellar tendon-bone graft (BPTB) was the first choice until the last decade, when the use of the hamstring tendons (HT), and first and foremost the semitendinosus tendon (ST), started to increase. Other alternatives, such as different types of synthetic grafts,^{46, 238} allografts,^{112, 154} quadriceps tendon grafts,⁶⁶ iliotibial band grafts,^{12, 152} grafts from the contralateral knee¹⁹⁹ and even the meniscus,²²⁶ have also been used. Several short-term, prospective, randomised studies comparing the use of BPTB and HT (i.e. ST or semitendinosus/gracilis (ST/G)) autografts have been published.^{2, 8, 19, 48, 49, 53, 91, 128, 161, 197} Several meta-analyses on the subject have also been published.^{21, 65, 71, 242} Studies evaluating the outcome in the medium to long term are more sparse.^{84, 131, 187} In the literature, subsequent problems after ACL reconstruction include donor-site morbidity, pain and the development of OA. Failures in terms of increased

laxity, re-rupture of the graft, patellar tendon rupture and fracture of the patella have been reported.^{23, 24, 34, 41, 115, 130, 138, 165} The reports in the short term reveal a higher frequency of donor-site morbidity after using BPTB autografts compared with HT autografts. However, in the long term, the difference appears to diminish.¹⁸ The graft-failure incidence is difficult to determine, since no uniform definition exists. In the literature, a range of between 1.5% and 22% has been reported.^{11, 212, 225} However, there appear to be no differences in failure rates between BPTB and HT autografts.¹⁸⁸ It has been reported that the risk of graft failure only increases during the first year as compared to sustaining an injury in the uninjured knee.^{163, 188}

Injuries to the ACL rarely occur in isolation. ACL injuries are often combined with complex ligamentous, meniscal, articular cartilage and bony injuries.^{9, 40, 159} It is difficult to predict how associated injuries will affect the outcome. An isolated ACL injury appears to increase the risk of OA at least 10-fold compared with an age-matched, uninjured population, i.e. from 1-2% to 10-20%.⁷⁰ Meniscectomy in a joint with intact ligaments including the ACL further increases the risk of OA even more (30-40%).¹⁸⁰ It has been reported that 50-70% of patients who have complete ACL injuries with associated injuries have radiographically visible OA changes 15 to 20 years after the ACL reconstruction.²¹⁰ The preventive effect of surgery on the development of OA remains unclear, or perhaps does not exist at all.^{39, 122, 234} Patients with OA in the knee generally experience swelling and pain during physically demanding activities. Range of motion (ROM) and muscle strength are usually diminished. The impaired function can be devastating and may lead to a change of work and recreational activity level and finally even assistance from the social services may become necessary.⁷⁰ Eventually, the symptoms may require a prosthetic replacement or, in younger patients, osteotomy or possibly joint fusion.⁷⁰ Since the kinematics of the ACL-reconstructed knee might differ compared with the normal knee, this could theoretically be one of the reasons for the development of OA.²³⁵ At present, only few studies compare the impact of graft selection on the development of OA.^{74, 104, 174, 181, 187}

The complexity of the ACL injury and its associated injuries leads to additional surgical challenges in the event of failures. Revision surgery is more difficult and demanding than primary ACL reconstruction. Careful patient evaluation is critical to the successful treatment of the failed ACL reconstruction. A thorough patient history should include the previous graft source, previous meniscal and articular cartilage injuries and their treatments, as well as any other surgical intervention to the knee. The surgical technique and graft selection should be individualised especially at ACL revision surgery. However, very little evidence based on clinical outcome studies after ACL revision surgery is available in the literature to guide the surgeon. The small number of patients and the lack of control groups limit the value of studies relating to ACL revision surgery that have been conducted so far.

In the literature, re-harvesting the ipsilateral patellar tendon as a graft for revision surgery has been suggested.^{35, 162, 237} Harvesting the patellar tendon for primary ACL reconstructions has long been regarded as the first choice and, since studies have shown a tendency towards total regeneration after a few years, the proposal to re-harvest it is a natural consequence.^{16, 153} One advantage for the patient is the avoidance of surgery in a new location in the body. However, other studies have failed to show regeneration of the patellar tendon after harvest and doubts have been raised about the quality of the tendon and its biomechanical properties, in addition to the risk of increased donor-site morbidity. Magnetic Resonance Imaging (MRI) assessments have shown that the patellar tendon has not normalised six years after harvesting its central third.²¹⁷ Reports on the histological appearance are sparse and contradictory. There are case reports describing an almost normal tendon,^{16, 37, 153} while others report abnormal tissue composition.^{14, 17, 29, 176, 216} Ultrastructural changes relating to the appearance of the cells, as well as the change in fibril size distribution after harvesting the central third of the patellar tendon, have been reported in the literature.²¹⁸ For ethical reasons, biomechanical testing in live human beings is impossible. Animal studies have, however, revealed inferior mechanical properties of the remaining patellar tendon.^{29, 116, 176} It therefore appears that the patellar tendon fails to regenerate to normal tendon after harvesting its central third and its re-use as a graft for revision ACL surgery could be disputed. In the literature, no histological and ultrastructural evaluation of the re-harvested patellar tendon in humans can be found. Moreover, performing this procedure offers an opportunity to analyse the tendon response to repeated surgery in general. It appears that there is a lack of knowledge in terms of the long-term results after ACL reconstruction using BPTB or HT autografts. The same can be said about the long-term course of the patellar tendon after multiple harvest for primary and revision ACL reconstruction.

REVIEW OF THE LITERATURE

The focus of this thesis is the behaviour of the patellar tendon after its central third has been re-harvested as a graft for ACL revision surgery. The tendon has been investigated and assessed using three different methods: MRI, light microscope and transmission electron microscope (TEM), in order to describe it macroscopically, histologically and ultrastructurally. Moreover, clinical and radiographic comparisons were made after using either BPTB or HT autografts for ACL reconstructions in the long term.

MRI

Several imaging studies reveal that the patellar tendon at the donor site does not normalise in the short or medium term after harvesting its central third. The thickness of the patellar tendon increases, at least up to two years post-operatively, irrespective of whether or not the donor-site defect is sutured.^{16, 17, 37, 101, 102, 120, 135, 153} Wiley and co-workers and Kartus and co-workers have made corresponding findings using ultrasonography (US).^{100, 229} Imaging studies of the donor site, after graft harvesting, show evidence of progressive healing. Berg assessed the patellar tendon eight months after its central-third had been harvested and found, using MRI, that the defect healed intrinsically with hypertrophic tendinous tissue.¹⁶ Coupens and co-workers used MRI to study 20 patients after harvesting the central third of the patellar tendon and demonstrated total resolution by 18 months. They concluded that the patellar tendon had the potential to re-model.³⁷ Meisterling and co-workers found that the width and thickness were slightly increased, but not to any significantly different degree from the normal tendon, two years after the reconstruction.¹³⁵ Correspondingly, Nixon and co-workers performed sequential MRI on 14 patients and found a reduction in the size of the defect and in signal intensity with time after surgery.¹⁵³ They concluded that the defect normalised at two years. Liu and co-workers, on the other hand, were not able to demonstrate complete healing of the donor site in six of 16 patients, seven years after the original surgery.¹²⁰ There are also studies which fail to show complete healing in the short term.^{17, 101, 102} Hsu and co-workers explained the initial increase in signal intensity seen on MRI at six months, followed by a decline at one year, as a result of initial synovial proliferation and revascularisation and subsequent cellular proliferation and re-modelling.⁸¹ The finding that the patellar tendon does not normalise within two to three years, as seen on MRI, is not unique. The corresponding finding has been reported in the Achilles tendon after rupture.^{124, 140} The long-term results are therefore of particular interest. In a prospective long-term serial MRI study of 19 patients, Svensson and co-workers concluded that the patellar tendon still displayed radiographic abnormalities six years after the harvesting procedure.²¹⁷ The MRI findings after re-harvesting the central third of the patellar tendon in humans have not yet been investigated.

Light microscopy and histology

In a normal tendon, about 70-80% of the dry weight of the tissue is collagen (predominantly type 1 collagen) and about 1% is extracellular matrix (ECM). Water accounts for 55-70% of the total wet weight and a substantial part of it is associated with the proteoglycans (PG).¹⁰⁹ The tensile strength of the tendon is dependent on intra- and intermolecular cross-links and the orientation, density and length of the collagen fibres.¹⁰⁹ The organisation and strength of the collagen fibres can be influenced by PGs. The PGs provide the lubrication that is necessary for the gliding function of the tendon. They consist of a protein core with attached glycosaminoglycans (GAG). The PGs may also influence the levels of the active growth factors involved in the healing process and the adhesion formation.^{78, 111} The PGs are therefore essential components in the tendon healing process. They influence cellular migration, as well as differentiation, and may also play a regulatory role in collagen fibril growth and in the three-dimensional arrangement of collagen fibrils.^{175, 193} Animal studies of the histological appearance of the patellar tendon after harvesting its central third have all failed to show any normalisation of the tendon. Using a goat model, Proctor and co-workers reported that the donor site, despite looking normal on MRI, revealed abnormal tissue composition when the biopsies were evaluated both histologically and ultrastructurally. They found ill-defined fascicles, woven collagen fibrils, poorly aligned with the longitudinal axis of the patellar ligament, in the central part of the tendon, 21 months after the harvesting procedure.¹⁷⁶ Correspondingly, in a study of lambs using a light microscope, Sanchis-Alfonso and co-workers found that the regenerated tissue at the harvest-site defect did not have the histological appearance of normal patellar tendon.¹⁸⁹ In a dog model, Burks and co-workers found that the entire patellar tendon was involved in scar formation three and six months after harvesting its central third.²⁹ In an analysis of the histological, biomechanical and structural properties of the re-harvested central-third patellar tendon in 12 greyhounds, LaPrade and co-workers revealed that collagen fibrils were hypercellular and oriented with the long axis at both six and 12 months.¹¹⁶ Biomechanical testing showed that the average failure load was significantly lower than that of controls at both six and 12 months. In humans, reports in the literature on the histological appearance of the patellar tendon after harvesting its central third are sparse and contradictory. In his case report on one patient, Berg verified the tendinous collagen structure of regenerated tissue histologically.¹⁶ The previously mentioned study by Nixon and co-workers reports that the histological appearance is indistinguishable from that of normal tendon in biopsies taken from two humans approximately two years after harvesting the central third of the patellar tendon.¹⁵³ On the other hand, Kartus and co-workers reported abnormal tissue composition in both the central and peripheral parts of the patellar tendon in 19 humans after harvesting its central third and leaving the defect open.¹⁰⁰ Similar findings have been reported by Battlehner and co-workers.¹⁴ They obtained open biopsies from eight humans, a minimum of 24 months after ACL reconstruction

using patellar tendon autografts. Using light and electron microscopy, they found that the patellar tendon did not regain the appearance of normal tendon during this period. However, in their study, the donor-site gap was closed surgically during the ACL reconstruction. Interestingly, the histopathology of a tendon subjected to long-standing achillodynia with abnormal fibre structure and increased GAG content resembles the post-harvest patellar tendon to some extent.¹⁴³

Transmission electron microscopy (TEM) and ultrastructure

Ultrastructurally, a bunch of collagen fibrils forms a collagen fibre, which is the basic unit of a tendon. The diameter of a fibril varies from 20 nm to 150 nm. The collagen fibril diameter increases from birth to maturity in animals.¹⁴¹ The tenoblasts have different shapes and sizes. Some are elongated, others rounded and still others polygonal.⁸⁶ Studies of the patellar tendon in humans after re-harvesting its central third using TEM are even sparser than light-microscopic studies. Battlehner and co-workers reported that the tendon does not recover “ad integrum” a minimum of two years after primary harvest.¹⁴ Svensson and co-workers also evaluated the patellar tendon, but six years after primary harvesting of its central third.²¹⁸ They concluded that the tendon had not recovered a normal ultrastructure either in the central or in the peripheral part, as seen using TEM. Using a goat model, Proctor and co-workers reported that the ultrastructure of the repair tissue, from the central third of the patellar tendon, was mainly composed of collagen fibrils with a small diameter.¹⁷⁶ This was noted 21 months after harvesting the central six mm of the patellar tendon. Using TEM in a dog model, LaPrade and co-workers reported that the re-harvested central third from the closed defect in the patellar tendon displayed increased fibril size and fibril packing at six months, compared with control tendons.¹¹⁶ However, at twelve months, no significant differences were registered. The ultrastructural findings in the patellar tendon following ACL reconstruction differ from changes preceding the spontaneous rupture of a tendon. In a study of 891 patients with spontaneously ruptured tendons using the light microscope and TEM, Kannus and co-workers generally found degenerative changes with mucoid degeneration, tendolipomatosis and calcifying tendinopathy in 97% of the patients.⁹⁵

ACL injuries and graft selection

The optimal graft choice for ACL reconstruction is unclear.^{63, 184} The ideal graft should have the characteristics of a normal ACL in terms of strength, stiffness, width and length in order to recreate the normal anatomy. It must also allow rigid fixation and rapid healing at the fixation sites to permit accelerated rehabilitation. The optimal graft would have no harvest-site morbidity and it would restore the patient’s activity level to pre-injury levels.²⁰⁵ Several graft options have been tried during the past few decades; they include grafts from the quadriceps tendon,⁶⁶ the iliotibial band^{12, 152} and the meniscus,²²⁶ grafts from the contralateral knee,¹⁹⁹ various synthetic grafts^{46, 238} and allografts.^{112, 154}

At present, the most commonly used grafts for ACL reconstructions are the BPTB and HT (ST; ST/G) autografts. The patellar tendon has high strength, high stiffness and solid bone-to-bone fixation. However, the graft is criticised for resulting in morbidity at the donor site, such as anterior knee pain, kneeling discomfort and loss of sensitivity in the infrapatellar area.^{45, 53, 117, 118} More infrequently, patellar tendon rupture and fracture of the patella have been observed.^{24, 34, 115, 130, 138} To avoid some of these problems, interest in using the HT as an autograft has increased. This graft typically uses the ST/G tendons or ST tendon alone. The tendons are looped to create a triple or quadruple strand structure and sutured to form the final graft. Twisting and braiding the strands reduces the tensile strength and stiffness and is not recommended.¹⁰⁸ However, concerns have been raised about other kinds of morbidity when using the HT autograft. Burks and co-workers noticed a significant and persistent atrophy, a frequent retraction of the ST muscle bundle and reduced strength of 13% to 20% in the hamstring one year after the reconstruction.²⁸ Sanders and co-workers reported post-operative persistent anteromedial sensory disturbances in 74% of patients one year after HT harvest.¹⁹¹ However, the reports are contradictory. Sensory deficits were only present in three of 76 patients when investigated six months after HT harvest by Soon and co-workers and the hamstring and the quadriceps muscles had recovered full strength.²¹¹ The major concerns about using HT grafts for ACL reconstruction involve the strength and stiffness of the flexor muscle after harvest. However, using the same fixation techniques for both grafts, Wilson and co-workers found that, in the quadruple state, the load failure of the HT graft was 2.42 kN compared with 1.78 kN for the patellar tendon graft.²³⁰ Ferretti and co-workers described regeneration of the ST after its harvest.⁵⁵ At two years, the entire central thicker portion of the specimens was occupied by well-oriented, tendon-like fibres and maturing tenocytes arranged in well-organised rows.

Several prospective, randomised short-term studies comparing the outcome when using the BPTB and HT autograft have been published.^{2, 8, 19, 48, 49, 53, 91, 128, 161, 197} In a meta-analysis of available studies, Freedman and co-workers reported that reconstruction using BPTB autografts had a lower rate of graft failure, less objective knee laxity and increased patient satisfaction.⁶⁵ However, it results in an increased rate of anterior knee pain compared with the use of HT autografts. In another meta-analysis, Yunes and co-workers found a trend towards improved stability using the BPTB autograft compared with the HT autograft and no significant differences in either complications or failure rate.²⁴² Recently, in a meta-analysis of all prospective, randomised clinical trials comparing BPTB and HT autografts with a minimum of two years of follow-up, Goldblatt and co-workers found eleven studies fulfilling the criteria for inclusion.⁷¹ The maximum follow-up time in their meta-analysis was a mean of 52 months. They found that the BPTB autograft was more likely to result in a normal Lachman test, normal

pivot-shift test, better KT-1000 arthrometer values and fewer patients with loss of flexion. The HT autograft, on the other hand, resulted in a lower incidence of patello-femoral crepitation, less kneeling pain and fewer patients with loss of extension. Biau and co-workers, in their meta-analysis, reported lower morbidity for HT autografts and weak evidence of improved stability using the BPTB autograft.²¹ In an extensive review, Beynnon and co-workers found that reconstruction using the four-strand HT autograft resulted in similar clinical and functional outcomes compared with the BPTB autograft.¹⁸ A few prospective studies comparing the use of BPTB with the use of HT autografts for ACL reconstruction, after more than five years, have been presented. When examining patients at a mean of 81 months, Ibrahim and co-workers found more patients with patello-femoral problems and loss of knee motion after using the BPTB autograft than after using the HT autograft.⁸⁴ However, they exclusively assessed male patients and only 77% of the patients who had initially been included attended the follow-up examinations. Matsumoto and co-workers found a reduced risk of morbidity at the donor site after using the bone-hamstring-bone autograft compared with the BPTB autograft, while the results for the remaining clinical parameters were comparable. The patients were tested a minimum of five years post-operatively.¹³¹ In their five-year follow-up of 64 patients, Sajovic and co-workers concluded that both BPTB and HT autografts provided good subjective outcomes and objective stability. They found no differences in terms of graft failures between the groups.¹⁸⁷

In an attempt completely to prevent morbidity problems associated with the use of autografts in ACL reconstruction, allograft material can be used. It offers several advantages, including reduced surgical time due to the opportunity for graft preparation pre-operatively, a lack of harvest site morbidity and the opportunity to select graft sizes. The surgical incisions can be smaller compared with using autografts and using allograft tissue makes simultaneous multiple ligament reconstructions possible.¹³⁴ The major concerns about using allografts include their biological incorporation, cost and the risk of disease transmission. In 2001, a patient died of *Clostridium sordellii* bacterial septic shock after receiving an infected allograft two days earlier.²⁰⁵ HIV transmission from a sero-negative donor infected with HIV is also possible. Due to fears of viral contamination in allografts, gamma irradiation is often used to decontaminate grafts. Unfortunately, gamma irradiation damages the tendon by splitting the alpha chains between the collagen molecules.³² The tensile strength of the tendon is substantially reduced after 3 Mrad radiation,⁶⁹ whereas virus particles are not necessarily inactivated by these doses.^{178, 208} To date, no synthetic grafts fulfil the criteria for a successful ACL reconstruction.^{18, 46}

Development and classification of OA

As stated by Woo and co-workers, the articular cartilage consists of scattered chondrocytes surrounded by an ECM composed of a macromolecular framework filled with water.²³⁶ The framework consists of collagen molecules; mainly type II, PGs and non-collagenous proteins. The concentration and organisation of collagen, PGs and water influence the tensile, compression, shear and permeability properties of articular cartilage. The chondrocytes may not be able to restore the normal cartilage after severe blunt trauma. Small defects can be repaired successfully, but larger defects usually fill with a fibrocartilagenous tissue.²³⁶ Usual symptoms of OA in the knee are a painful and swollen joint with decreased ROM. Sometimes pain at rest, including disturbed sleep at night, occurs. Approximately 5% of the population between the ages of 35 and 54 years have radiographic signs of OA in the knee.¹⁷⁰ Of these, the majority have suffered a previous knee injury. Degenerative changes in the knee after ACL injury, as well as after ACL reconstruction, in the long term are common.^{39, 122, 234} Radiographic changes indicating OA are found in 60-90% of patients with a rupture of the ACL, either isolated or in combination with meniscus or collateral ligament injuries, 10-15 years after the injury.^{122, 133, 151, 194, 210, 234} Meniscectomy, in combination with ACL rupture, appears to lead to degenerative changes and may lead to a less favourable clinical outcome.^{3, 39, 93, 103, 136, 201, 240} Hart and co-workers used Single-Photon Emission Computed Tomography (SPECT) ten years after ACL reconstruction using BPTB autografts and found a prevalence of OA of 7% when associated with intact menisci and 13% if partial meniscectomy had been performed.⁷⁶ Furthermore, there is an increased incidence of meniscectomies at the time of ACL reconstruction in knees with chronic injury compared with acutely injured ones.⁹³ In the literature agreement seems to exist about the timing of ACL reconstruction. Johma and co-workers and Seon and co-workers support early reconstruction, after discovering a lower incidence of OA in patients who underwent ACL reconstruction within 12 weeks and six months respectively compared with delayed reconstruction.^{93, 195} These reports support the concept that early ACL reconstruction should be recommended before repetitive micro-trauma results in further meniscal damage. In the event of a chronic ACL-deficient knee, the menisci are important for joint stability.^{57, 207} With regard to ageing and OA, it has been reported that the frequency of OA is higher in those over 25 years of age at the time of surgery.^{70, 183, 195}

The actual effect of ACL reconstruction on the development of OA is unclear. Von Porat and co-workers found a 41% prevalence of radiographic OA changes, of Kellgren & Lawrence grade 2 or higher, in male soccer players, 14 years after ACL injury.^{106, 234} No differences were seen between surgically and non-surgically treated patients.²³⁴ In a similar study, Lohmander and co-workers reported that 51% of female soccer players displayed radiographic changes, of Kellgren & Lawrence Grade 2, 12 years after the injury.¹²² Daniel and co-workers found an

increased prevalence of OA in surgically treated patients after ACL injury compared with conservatively treated patients, in a non-controlled study.³⁹ In a meta-analysis involving 33 clinical follow-up studies, the efficacy of ACL reconstruction in delaying the progression of OA was not substantiated.¹²³ In a randomised study with a 15-year follow-up of 100 patients, Meunier and co-workers found that an ACL repair itself was not able to reduce the risk of OA. The status of the menisci, on the other hand, was found to be the most important predictor of developing OA. However, one-third of the non-surgically treated patients subsequently had their knees reconstructed due to instability.¹³⁶ Additional studies have not shown that surgical treatment reduces the risk of OA.⁵⁸

The role of an appropriate graft choice in the development of OA is of interest. In a cohort study, Roe and co-workers found radiographic evidence of OA according to the International Knee Documentation Committee (IKDC) system in the knee joint seven years after ACL reconstruction in 45% of patients treated with BPTB autografts and in 14% of patients treated with an HT autograft.¹⁸¹ In their prospective, randomised study with a five-year follow-up, Sajovic and co-workers observed a higher prevalence of OA using BPTB autografts.¹⁸⁷ The radiographic evaluation was made according to the IKDC system and revealed a prevalence of 50% after using the BPTB autograft and 17% after the use of HT autografts. Similar findings were reported in a 10-year prospective, controlled comparison by Pinczewski and co-workers, with a prevalence of 53% radiographic OA findings using BPTB autografts and 31% after the use of HT autografts according to the IKDC grading system.¹⁷⁴ On the other hand, in a randomised, prospective study by Harilainen and co-workers with a five-year follow-up and the same method of radiographic evaluation, i.e. the IKDC system, no differences in the prevalence of OA changes were found between the BPTB and HT autograft.⁷⁴ One possible explanation given by Roe and co-workers and Pinczewski and co-workers is that changes in knee kinematics in gait result in reduced knee flexion moment and thereby the increased loading of the medial compartment, where the OA is predominantly located.^{174, 227} However, Chouliaras and co-workers and Woo and co-workers recently found no differences in knee kinematics either in the anterior-posterior direction or during tibial rotational load with quadruple HT and BPTB autografts.^{33, 235} To illuminate this issue completely, a dynamic Radio Stereometric Analysis (RSA) technique to examine the knee kinematics after using different graft types appears to be necessary.

Non-mechanical factors such as cytokines, tumour necrosis factor and neurogenic deficiencies^{30, 31, 129, 160, 190} are also known to be involved in the development of OA. New molecular biology techniques have provided an insight into the function of the cells during the onset and progression of OA.¹⁹⁰ In OA, the strict regulation of matrix turnover is disturbed. It has been suggested that biochemical factors, such as catabolic and anabolic cytokines and growth hormones, influence the

chondrocytes and contribute to the process of OA development. In patients with ACL-deficient knees, increased concentrations of the chondrodestructive cytokine IL-1 β and the growth factor TNF- α have been found.¹²⁹

At present, there are several instruments available for evaluating degenerative changes in the joint, which make comparisons between various studies difficult. In 1994, a consensus meeting was held in conjunction with the American Academy of Orthopedic Surgeons, the National Institutes of Orthopaedic Surgeons, the National Institutes of Health and the World Health Organisation with the aim of presenting a minimum set of standard methodologies for assessing the progression of OA in the hip and knee joints.⁴² The recommendation was that radiographic evaluation would be the major outcome measure to assess OA over time. The use of molecular marker assays to study OA processes was identified, but none could be specifically recommended as providing a measure of disease progression.^{121, 222} MRI and arthroscopy were considered to be among other important technologies for documenting morphological changes in OA.

In 1948, Fairbank presented a grading system which is still in use (Table 1).⁵¹ His classification relates primarily to mild changes ranging from flattening of the condyles and subchondral sclerosis to joint space narrowing. In 1957, Kellgren and Lawrence¹⁰⁶ introduced a radiographic classification, followed by an OA grading system for the knee presented by Kellgren alone in 1963.¹⁰⁵ In 1968, Ahlbäck proposed a grading system for OA in the knee from mild stages with joint narrowing to severe re-modelling of the bone (Table 2).⁴ He also stressed the importance of taking weight-bearing radiographs with the knee flexed at approximately 20°. At long-term follow-up evaluations after knee injuries, most radiographic changes can be described using Fairbank's and Ahlbäck's classification systems.⁷⁰ Moreover, in recent years, the IKDC has recommended an additional evaluation system based

Table 1.

Observation	Classification
Flattening medial/lateral	Yes/no
Narrowing medial/lateral	Yes/no
Ridging medial/lateral	Yes/no

Fairbank's radiographic classification system for degenerative changes

Table 2.

Stage	Radiographic findings
I	Joint space narrowing (<50%)
II	Joint space obliteration
III	Minor bone attrition (<5mm)
IV	Moderate bone attrition (>5mm)
V	Severe bone attrition, subluxation

Ahlbäck's radiographic classification of OA

on four grades. This grading system has similarities to Ahlbäck's classification, but it focuses more heavily on minor changes (A, normal; B, minimal changes and barely detectable joint space narrowing; C, minimal changes and joint space narrowing up to 50%; D, more than 50% joint space narrowing).

AIMS OF THE STUDY

- To investigate whether the donor site in the patellar tendon as seen on MRI has normalised 10 years after re-harvesting the patellar tendon in ACL revision surgery
- To evaluate whether there is a change in the clinical outcome and the appearance of the patellar tendon donor site as seen on MRI between the two- and 10-year follow-up assessments after re-harvesting the patellar tendon for ACL revision surgery
- To compare the clinical outcome of ACL reconstruction after using the subcutaneously harvested central-third BPTB graft with the use of a triple or quadruple ST-tendon graft in the medium to long term
- To evaluate the radiographic prevalence of OA and the clinical outcome in the long term after ACL reconstruction using either BPTB or HT autografts
- To evaluate the influence of associated meniscal injuries on the prevalence of OA in the long term after ACL reconstruction.
- To evaluate and compare the histological and ultrastructural appearance of the central and peripheral parts of the patellar tendon with those of normal patellar tendon ten years after the re-harvesting procedure in ACL revision surgery

PATIENTS AND DEMOGRAPHICS

All the patients were considered to have a unilateral ACL injury or failure of previous ACL reconstruction, clinically verified by a history of trauma, a positive Lachman test and/or positive pivot-shift test. The exclusion criteria were associated posterior cruciate ligament injury, more than +1 medial and/or lateral collateral ligament laxity, previous knee ligament surgery (except in *Studies I* and *IV*) or known contralateral knee ligament injury and radiographically visible OA at the time of inclusion. All the patients included in the studies are presented in Table 3.

Table 3.

	Total number of patients included in the studies	Allocation of patients
Study I	14 patients	2 patients were <i>only</i> included in Study I 12 patients were also included in Study IV
Study II	71 patients	11 patients were <i>only</i> included in Study II 60 patients were also included in Study III
Study III	124 patients	64 patients were <i>only</i> included in Study III 60 patients were also included in Study II
Study IV	12 patients	No patients were <i>only</i> included in Study IV 12 patients were also included in Study I

NOTE: A total of 149 unique patients were included in Studies I-IV.

Study I

Between February 1993 and November 1994, 14 consecutive patients (5 females, 9 males) in need of ACL revision surgery underwent reconstruction using re-harvested ipsilateral patellar tendon autografts and interference screw fixation. The median time since the primary ACL reconstruction was 64 months (range 15-132). The median age at revision surgery was 28 years (range 23-39). All primary ACL reconstructions were performed using an open technique. Six patients had previously undergone reconstruction involving the medial third of the patellar tendon and eight involving the central third. The cause of failure was an insufficient graft due to the drill holes on the tibial, femoral or both sides being given an overly anterior position in 12 patients and a new significant trauma in two patients. The follow-up assessments were performed by the same independent observer at 26 (range 20-35) and 115 (range 102-127) months. A clinical examination was performed on 14 patients at two years and 11 patients at 10 years. One patient underwent a second revision procedure using an HT autograft six years after the index operation due to a trauma. This patient was excluded from the clinical assessments at 10 years.

Study II

Between September 1995 and May 1998, 71 patients (22 females, 49 males) suffering from ACL deficiency were prospectively randomised for reconstruction using either an ipsilateral BPTB autograft or an ipsilateral triple/quadruple ST autograft. The randomisation was carried out using closed envelopes. The initial aim was to randomise 80 patients. However, due to the time factor, the study was terminated after randomising 71 patients. All the patients had previously participated in a two-year follow-up⁴⁵ and 14 of the patients had previously also participated in a multi-centre study.¹¹⁸ In 34 patients, the central third of the BPTB autograft was used and, in 37 patients, the ST was used in the form of a triple (n=14) or quadruple (n=23) autograft. The groups were comparable in terms of gender, age, pre-injury Tegner activity level and time between the injury and the index operation. The pre-injury Tegner activity level was a median of 9 in both groups. Sixty-eight (96%) patients attended the follow-up at a median of 86 months (68-114). One patient in each group was lost to follow-up because we were unable to locate them and one patient in the BPTB group who had suffered a traumatic graft rupture did not feel motivated to participate in the follow-up examination. Moreover, one patient in the BPTB group and two in the ST group suffered a traumatic graft rupture during the follow-up period and were examined and reported as failures, but excluded from the calculations. The majority of index injuries occurred during contact sports (68%) and non-contact sports (16%), see Table 4.

Table 4.
The cause of injury

	BPTB (n=31)	HT (n=34)	Significance
Contact sport	22	22	
Non-contact sport	5	6	n.s.
ADL	0	3	(p=0.38)
Traffic accident	2	3	
Other	2	0	

Study III

Between April 1995 and May 1998, three prospective, randomised studies were performed at our institution. These studies involved a total of 128 patients, suffering from a symptomatic unilateral chronic ACL deficiency.^{44, 45, 118} From this heterogeneous cohort, 124 patients were included in the present study and four patients were excluded due to an ACL re-rupture. At follow-up, a median of 86 months (range 67-111) after the index ACL reconstruction 113/124 patients (91%) underwent standard weight-bearing radiographs and 111/124 underwent clinical assessments. Seventy-two patients underwent reconstruction using ipsilateral BPTB autografts and 41 patients using either ipsilateral triple ST autografts or quadruple ST/G autografts (32 ST, 9 ST/G). The median age at surgery was 28 years (range 15-59) and the reconstruction was performed a median of 18 months (range 2-360) after the injury. The pre-injury Tegner activity level was a median of 9 in both groups. Most injuries occurred during contact sports (71%) and non-contact sports (15%) (Table 5). Two patients in the BPTB group suffered clinical signs of bacterial arthritis, both at four weeks post-operatively, but both with negative cultures. One patient in the HT group suffered the same symptoms but with positive cultures, two weeks post-operatively. All three patients healed after arthroscopic lavage and antibiotics and were thus kept in the study.

Table 5.
The cause of injury

	BPTB (n=72)	HT (n=41)	Significance
Contact sport	53	29	
Non-contact sport	10	7	n.s.
ADL	2	4	(p=0.38)
Traffic accident	3	1	
Other	2	0	
Missing values	2	0	

Study IV

Twelve consecutive patients (4 females, 8 males) in need of ACL revision surgery underwent reconstruction using re-harvested ipsilateral central-third BPTB autografts between February 1993 and November 1994. The median time since the first reconstruction was five years (range 30-132 months) and the median age at revision surgery was 27 years (range 23-39). All the primary reconstructions were performed using an open technique. Six patients had primary reconstructions involving the ipsilateral medial third and six had primary reconstructions involving the ipsilateral central third of the patellar tendon as a graft. Biopsies were obtained a median of 116 months (102-127) after the revision procedure. The biopsy specimen from one of the 12 patients contained an insufficient amount of tissue and was thus excluded from the histological evaluation. Ten patients served as controls. The median age of these patients was 27 years (range 19-40).

METHODS

Blinded observers

In *Study I*, one physiotherapist, who was not involved in the rehabilitation, performed all the pre- and post-operative clinical assessments.

In *Studies II and III*, two physiotherapists, who were not involved in the rehabilitation, performed the pre- and post-operative clinical assessments. The physiotherapists were blinded to the aim of the study, but not to the type of surgical technique that had been used.

The surgical procedure

All the patients underwent ACL surgery by one senior surgeon using a standardised endoscopic technique.

In *Studies II and III*, in the BPTB group, the arthroscopic transtibial technique¹⁸⁵ and interference screw fixation¹¹³ were used during the index procedures. The central third of the patellar tendon was harvested through two 25-mm long vertical incisions, one over the apex of the patella and the other just above the tibial tubercle. The graft was tunneled subcutaneously under the paratenon with the aim of protecting the infrapatellar nerve and its branches and leaving the major part of the paratenon intact, as described previously by Kartus and co-workers.⁹⁷ The proximal bone block was sized to 9 mm and the distal bone block to 10 mm. The bone tunnels were prepared in a standard transtibial fashion. The femoral tunnel was placed at approximately 10.30 in the right knee and 01.30 in the left knee and the tibial tunnel was placed anterior to the normal posterior cruciate ligament in the ACL footprint. A 7 mm and a 9 mm Acufex® (Acufex, Microsurgical Inc., Mansfield, MA, USA) “silk” interference screw were used on the femoral and tibial side respectively (Fig. 1).

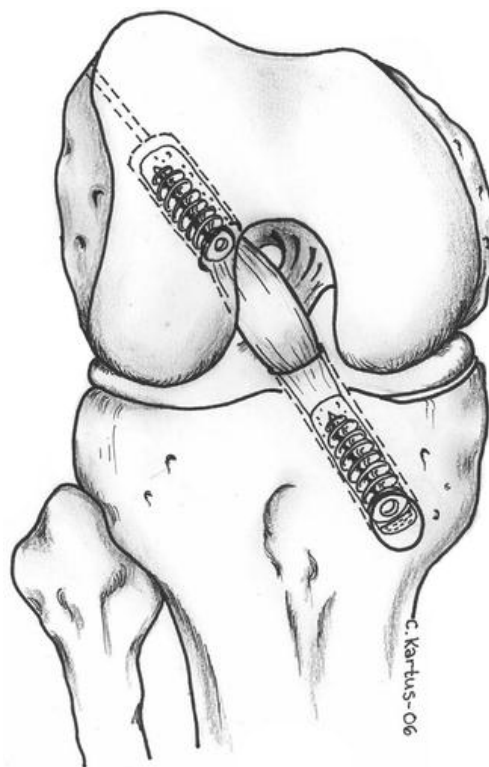


Figure 1. Using the BPTB graft, a 7 mm and a 9 mm interference screw were used on the femoral and tibial sides, respectively. (Copyright Catarina Kartus)

In the HT group in *Study II* and the ST group in *Study III*, the graft was harvested through a 3-cm oblique incision over the pes anserinus. The tendons were palpated and the sartorius fascia was incised parallel to the fibres of the fascia just above the thicker and more distally inserted ST tendon. After the vinculae had been cut under visual control, the ST or ST/G tendons were harvested with a semi-blunt, semi-circular open tendon stripper (Acufex, Microsurgical Inc., Mansfield, MA, USA). The tendon was prepared for a triple or quadruple graft, depending on the study to which the patient had been allocated. The minimum accepted length for the final graft was 7 cm. Two no. 5 non-resorbable Ticon® (Sherwood Medical, St Louis, MO 63103, USA) sutures were used as the lead sutures at the distal and proximal ends. Resorbable no. 1 Vicryl® (GmbH & Co. KG, D-22851 Norderstedt) sutures were used for the modified baseball stitches at the distal and proximal ends of the HT graft. A 7 mm soft threaded (RCI® Smith and Nephew, Inc, Andover, MA USA) interference screw was used on both the femoral and tibial side.³⁶ After the femoral screw had been inserted, firm traction was applied to the graft during insertion of the tibial screw, with the knee in hyperextension, in both the BPTB group and the HT group (Fig. 2).

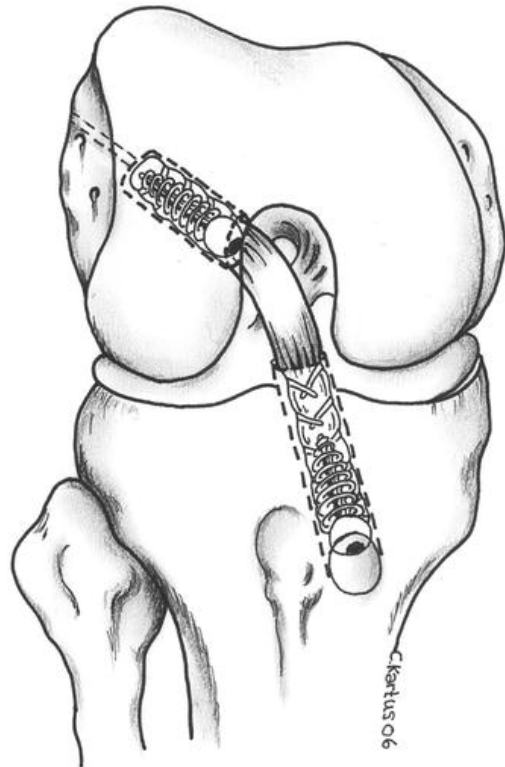


Figure 2. Using the ST/G graft, a 7 mm soft threaded RCI® interference screw was used on both the femoral and tibial sides. (Copyright Catarina Kartus)

In *Studies I* and *IV*, the standardised arthroscopic technique, using re-harvested ipsilateral patellar tendon autografts and interference screw fixation at both the femoral and tibial sides, was performed. The graft was harvested from the central third of the remaining patellar tendon. A 7- to 8-cm long single vertical incision was used and, at the completion of surgery, the tendon defect was left open and the paratenon was carefully sutured. No bone grafting of the harvest-site defect was performed. Remaining portions of the torn ACL were excised and a notch plasty was performed to prevent impingement of the graft. All previously inserted screws were removed and no bone grafting was required.

Registration of additional surgery

Additional surgery at the index operation was registered in the evaluation protocol (Fig. 9) and the patients' files.

MRI examination

One independent experienced radiologist evaluated all the MRI examinations. A Siemens™ (Erlangen, Germany) Magnetom 1.0 Tesla and a flexible knee coil were used. Both the knees were examined in slight flexion. A three-dimensional dual echo steady state (DESS) sequence was used and a three-dimensional reconstruction program was used to obtain axial reconstructions, from which values for the width and thickness were calculated through the mid-point along the length of the patellar tendon from the apex of the patella to the insertion at the tibial tubercle (Fig. 3). The mid-point of the patellar tendon at the donor site was then evaluated in terms of gap size (area corresponding to non-tendinous-like tissue signals), (Figs. 4 A-B) in the axial dimension. All the measurements were made using a Siemens™ evaluation unit using computerised distance measurements and standardised settings. The intraobserver standard deviation (SD) of the difference between two measurements was 0.67 mm, as assessed by re-evaluating 10 randomly selected examinations of the thickness of normal patellar tendons, without knowledge of the primary result.



Figure 3.

Values of the width and thickness were calculated through the mid-point along the length of the patellar tendon from the apex of the patella to the insertion at the tibial tubercle.

(With kind permission of Springer Science + Business Media)

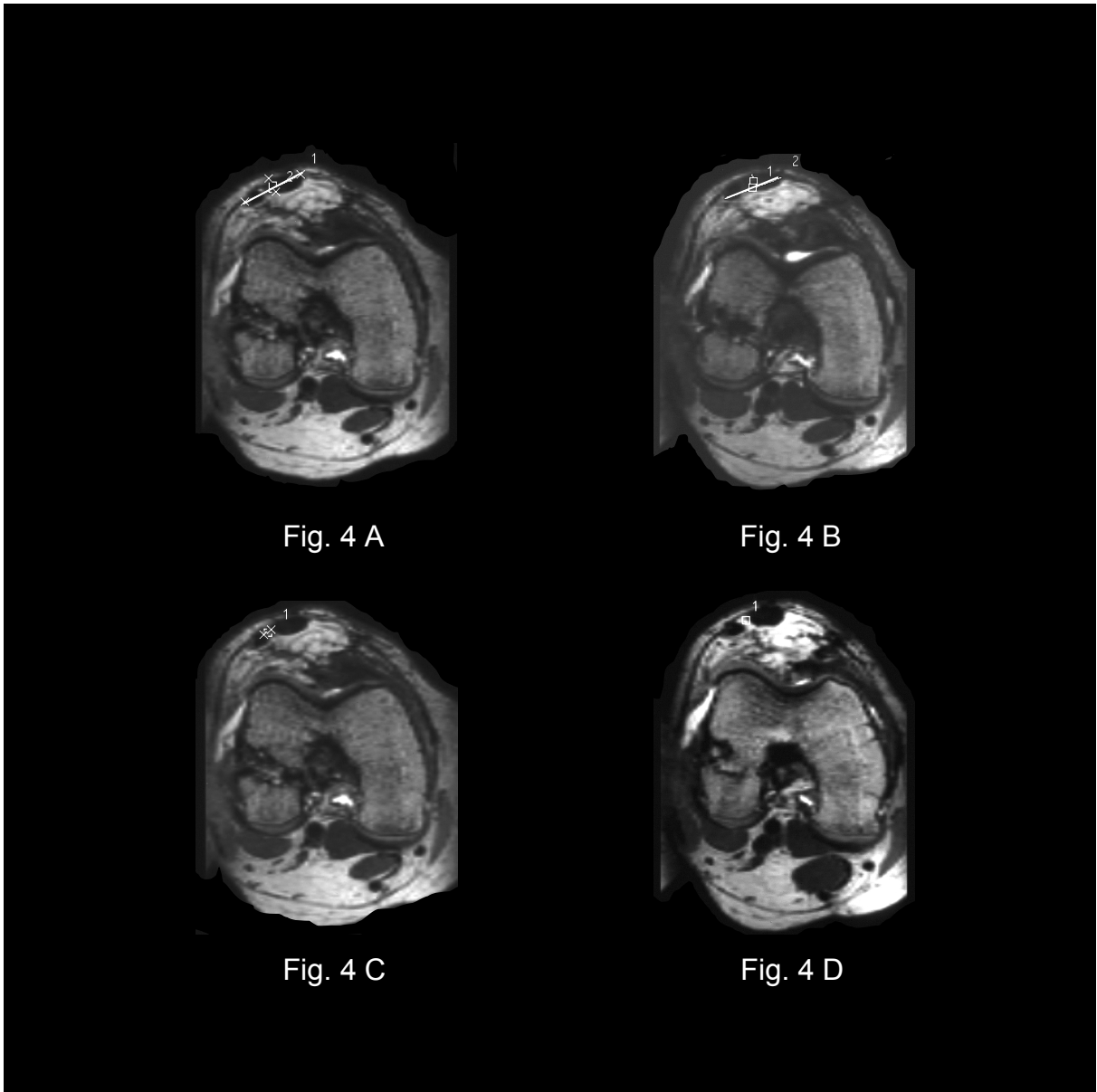


Figure 4 A-D.

Measurements of the width and thickness two years (A) and 10 years (B) as well as measurements of the donor-site gap two years (C) and 10 years (D) after re-harvesting the patellar tendon in a female patient revealed no difference between the examinations respectively. (Copyright Jüri Kartus)

Standard radiography

Standard weight-bearing radiographic examinations in the anterior-posterior (AP) and lateral views (Figs. 5 A and B), with 15⁰-30⁰ flexion of the knee, were taken and classified according to the Ahlbäck and the Fairbank rating systems (Table 1 and 2).^{4, 51} For the Fairbank system, the cumulative number of positive findings, from 0 to 6, was calculated for each patient. An independent musculoskeletal radiologist, blinded to the type of graft, interpreted the radiographs. The intra-rater reproducibility analysis revealed kappa values between 0.55 and 1.00, when classifying and re-classifying the results of the Ahlbäck and Fairbank rating systems for 20 randomly selected patients. The time period between these classifications was 12 months. The OA changes in the femuro-patellar joint were classified as none, minor, moderate or severe.



Figure 5 A-B.

Standard weight-bearing X-ray examination in the lateral (A) and AP (B) views in a 35-year old male, 102 months after ACL reconstruction using a BPTB autograft (Copyright Mattias Lidén).

Biopsy procedures

Four biopsy specimens (two central and two lateral) were obtained from the patellar tendon of each patient. One central and one lateral specimen were used for light-microscopic evaluation and, in the corresponding manner, one central and one lateral specimen were used for TEM evaluation. The biopsy specimens were obtained under US guidance with a free-hand technique using a 1.2 mm Tru-cut Monopty™ instrument (Bard Inc., Covington, GA, USA) (Fig. 6). This is a light-weight metal handle with a pre-attached disposable biopsy needle. When fired, the gun needle moves in two steps. During the first step, the inner stylet punctures the target and, in the second step, an outer cannula follows the path of the stylet, covering the sample notch and thus capturing the sample. Local anaesthesia with adrenalin (5-10 ml) was given subcutaneously and in the fat pad of Hoffa. Through multiple small incisions, biopsy specimens were obtained from each patient, centrally from the donor-site gap area and peripherally from the lateral part of the patellar tendon. Each core biopsy specimen was placed separately in a coded tube. The samples that were obtained had a length of 5-10 mm and a maximum diameter of 1.2 mm. This procedure has previously been shown to cause negligible discomfort to patients.¹⁰⁰



Figure 6.

The specimens were obtained under ultrasonography-guidance with a free-hand technique using a 1.2 mm Tru-cut Monopty™ instrument. (Copyright Jüri Kartus)

Control specimens

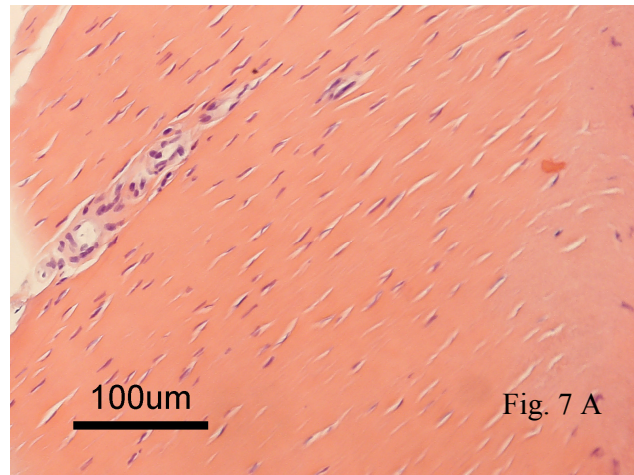
Tendon control specimens were obtained in an open fashion from the central third of the patellar tendon when harvesting the BPTB autograft in eleven patients (one female and ten males) treated with the same type of ACL reconstruction. The median age of the control patients was 27 (19-40) years. These patients had no previous history of pain in the patellar tendon region and, in previous arthroscopic procedures, the anterolateral and anteromedial portals had been used, thus avoiding damage to the patellar tendon.

Histology

The biopsy specimens were fixed in 10% neutral-buffered formalin, embedded in paraffin and sectioned at 4-5 μ m. The sections were stained with hematoxylin and eosin (HE) to evaluate fibre structure, cellularity and vascularity (Figs. 7 A and B, fig. 8). The Alcian Blue (pH 2.5)/Periodic Acid-Schiff (AB/PAS) method was used to detect elevated levels of GAGs.

Figures 7 A and B.

A. Light microscopic view of patellar tendon tissue obtained by needle biopsy from the central part of the patellar tendon 10 years after reharvesting its central third, showing unparallel collagen fibres with a vessel in the upper left quadrant. The cellularity is slightly increased. (Approximate original magnification 200x). (With kind permission of SAGE publications)



B. Light microscopic view of patellar tendon tissue obtained by needle biopsy from the lateral part of the patellar tendon 10 years after reharvesting its central third. The cellularity and vascularity are slightly increased. (Approximate original magnification 200x). (With kind permission of SAGE publications)

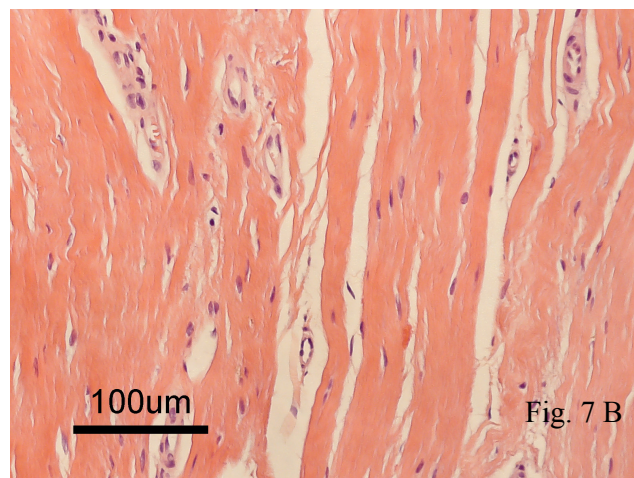
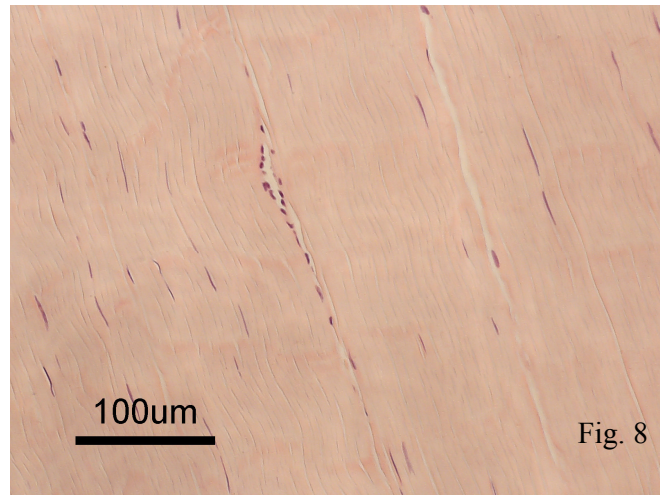


Figure 8.

Light microscopic view of normal patellar tendon tissue obtained in an open fashion from a 25 year old man at ACL surgery. The fibres are parallel and densely packed with flattened nuclei in between. (Approximate original magnification 200x). (With kind permission of SAGE publications)



Evaluation of the biopsies

All the specimens were examined simultaneously using a light microscope by a pathologist and an orthopaedic surgeon, both with a specific interest in and knowledge of tendon pathology. The biopsy specimens were evaluated using a semi-quantitative (non-parametric) grading system for the tendon pathology.¹⁰⁰ Grading was based on a four-point scoring system (Table 6). The fibre structure, vascularity and level of GAGs were graded after examining the entire section. The number of cells was estimated in a high-power field representative of the section. The biopsy specimens from the same patient were evaluated in paired fashion and, for every specimen and every parameter, the two examiners reached agreement on the classification.

Table 6.

Histological classification

A semi-quantitative four-point scoring system was used to evaluate the biopsies.¹⁰⁰

	Grade 0	Grade 1	Grade 2	Grade 3
Fibre structure	Straight parallel, packed fibres, with slight waviness	Slight separation of fibres, increased waviness	Separation of fibres, deterioration of fibres	Complete loss of fibre structure and hyalinisation
Cellularity	< 100 cells/high-power field (HPF)	100-199 cells/HPF	200-299 cells/HPF	> 300 cells/HPF
Vascularity	Vessels running parallel to the collagen fibre bundles in the septa	Slight increase in vessels, including transverse vessels in the tendon tissue	Moderate increase in vessels within the tendon tissue	Markedly increased vascularity with clusters of vessels
Glycosamino-glycans	No alcianophilia	Slight alcianophilia between the collagen fibres	Moderate increase in alcianophilia	Markedly increased alcianophilia forming blue lakes

Transmission electron microscopy (TEM)

Tendon specimens were collected and immediately fixed in 2% glutaraldehyde and 0.5% paraformaldehyde in 0.1M sodium cacodylate buffer containing 0.1M sucrose and 3mM CaCl₂ (pH 7.4) at room temperature for 30 minutes, followed by 24 hours at 4°C. The specimens were rinsed in 0.15 M sodium cacodylate buffer containing 3mM CaCl₂ (pH 7.4) and post-fixed in 2% osmium tetroxide in 0.07 M sodium cacodylate buffer containing 1.5 mM CaCl₂ (pH 7.4) at 4°C for two hours, then dehydrated in ethanol followed by acetone and embedded in LX-112 (Ladd, Burlington, Vermont, USA), for both longitudinal and transverse sectioning. Ultra-thin sections (approximately 40-50 nm) were cut and contrasted with uranyl acetate followed by lead citrate and examined in a Tecnai 10 microscope (Fei company, Eindhoven, the Netherlands) at 80 kV. Longitudinally oriented specimens were screened at low magnification (x3000) for morphological evaluation. From transversely oriented specimens, two to four randomly selected areas were taken and the fibril diameter was measured on printed copies (x101 000) using a Zeiss TGZ-3 particle-size analyser, grouped in five size classes (0-30 nm, 31-60 nm, 61-90 nm, 91-120 nm and >121 nm) and presented as the relative distribution.²²⁸ A minimum of 100 fibrils were analysed in each specimen.

The clinical examination test

A special protocol was developed for the pre-operative and/or post-operative clinical evaluations and was used in all studies (Fig. 9). The physiotherapists performed the evaluations, apart from the Lysholm knee-scoring scale, which was patient administered.

KNEE EVALUATION PROTOCOL, NÄL, TROLLHÄTTAN

Name _____ No _____

Sex female male

Age at op _____

Injured side left right

Dominant side left right

Contralateral side normal yes no

Cause of injury contact sport none contact sport ADL work other

Previous surgery none arthro men ACL diagn arthro open men other

Date of reconstruction _____

Type of operation within 2 months after injury _____ weeks after injury
 more than 2 months after injury _____ months after injury
 Revision surgery _____ months after recon

Injuries at reconstruction None but ACL LCL P cap Other
 Med men MCL Artrosis ACL
 Lat men PCL Cartilage

Type of graft BTB 11 BTB contra lat ST ST+G
 BTB 21 BTB reharvest FL Other

Index procedure ACL endo PCL LCL Men sut lat Part men lat
 ACL 21 MCL Men sut med Part men med Other

Twisted graft fixation yes no

Prelension yes no

Hospital stay _____ days

Brace yes no

Sickleave _____ days

Early problems (< 3 months) None Wound inf Deep inf Other
 Delayed wound healing Ext def Trombosis

Fp I _____ months pop Fp II _____ months pop Fp III _____ months pop Fp IV _____ months pop

ROM Preop _____ ext flex Fp I _____ ext flex Fp II _____ ext flex Fp III _____ ext flex Fp IV _____ ext flex

ROM contralateral side _____ ext flex

KNEE EVALUATION PROTOCOL
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Manual MCL compared with contralateral side

Preop 0 1+ 2+ 3+ Fp I 0 1+ 2+ 3+ Fp II 0 1+ 2+ 3+ Fp III 0 1+ 2+ 3+ Fp IV 0 1+ 2+ 3+

Manual LCL compared with contralateral side

Preop 0 1+ 2+ 3+ Fp I 0 1+ 2+ 3+ Fp II 0 1+ 2+ 3+ Fp III 0 1+ 2+ 3+ Fp IV 0 1+ 2+ 3+

KT 1 000 15 lbs 20 lbs

Prop	I	NI	D	I	NI	D
A						
P						
T						

KT 1 000 15 lbs 20 lbs

Fp I	I	NI	D	I	NI	D
A						
P						
T						

KT 1 000 15 lbs 20 lbs

Fp II	I	NI	D	I	NI	D
A						
P						
T						

KT 1 000 15 lbs 20 lbs

Fp III	I	NI	D	I	NI	D
A						
P						
T						

KT 1 000 15 lbs 20 lbs

Fp IV	I	NI	D	I	NI	D
A						
P						
T						

Manual Lachmann compared with contralateral side

Prop 0 1+ 2+ 3+ Fp I 0 1+ 2+ 3+ Fp II 0 1+ 2+ 3+ Fp III 0 1+ 2+ 3+ Fp IV 0 1+ 2+ 3+

Total AP 70° compared with contralateral side

Prop 0 1+ 2+ 3+ Fp I 0 1+ 2+ 3+ Fp II 0 1+ 2+ 3+ Fp III 0 1+ 2+ 3+ Fp IV 0 1+ 2+ 3+

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Posterior sag 70° compared with contralateral side

Prop 0 1+ 2+ 3+ Fp I 0 1+ 2+ 3+ Fp II 0 1+ 2+ 3+ Fp III 0 1+ 2+ 3+ Fp IV 0 1+ 2+ 3+

Pivot shift compared with contralateral side

Prop 0 1+ 2+ 3+ Fp I 0 1+ 2+ 3+ Fp II 0 1+ 2+ 3+ Fp III 0 1+ 2+ 3+ Fp IV 0 1+ 2+ 3+

Reversed pivot shift compared with contralateral side

Prop 0 1+ 2+ 3+ Fp I 0 1+ 2+ 3+ Fp II 0 1+ 2+ 3+ Fp III 0 1+ 2+ 3+ Fp IV 0 1+ 2+ 3+

Firm end point

Prop yes no Fp I yes no Fp II yes no Fp III yes no Fp IV yes no

Firm end point contralateral side

yes no

One leg hop

Prop _____ % Fp I _____ % Fp II _____ % Fp III _____ % Fp IV _____ %

Paresthesia (ant-post) x (prox-dist)

Prop _____ cm² Fp I _____ cm² Fp II _____ cm² Fp III _____ cm² Fp IV _____ cm²

Subjective femoro-patellar pain

Prop yes no Fp I yes no Fp II yes no Fp III yes no Fp IV yes no

Femoro-patellar score

Prop _____ Fp I _____ Fp II _____ Fp III _____ Fp IV _____

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Donor site pain

Prop no yes Fp I no yes Fp II no yes Fp III no yes Fp IV no yes

apex apex apex apex apex
 mid mid mid mid mid
 tuberositas tuberositas tuberositas tuberositas tuberositas
 pes pes pes pes pes
 thigh dorsal thigh dorsal thigh dorsal thigh dorsal thigh dorsal
 screw screw screw screw screw

Patellar tendon donor site union (palpatory)

Fp I yes no Fp II yes no Fp III yes no Fp IV yes no

Kneeling

Preop OK Not pleasant Difficult Impossible Fp I OK Not pleasant Difficult Impossible Fp II OK Not pleasant Difficult Impossible Fp III OK Not pleasant Difficult Impossible Fp IV OK Not pleasant Difficult Impossible

Knee walking

Preop OK Not pleasant Difficult Impossible Fp I OK Not pleasant Difficult Impossible Fp II OK Not pleasant Difficult Impossible Fp III OK Not pleasant Difficult Impossible Fp IV OK Not pleasant Difficult Impossible

IKDC (Group grade)

Subjective function	Preop	Fp I	Fp II	Fp III	Fp IV
	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D
Subjective symptoms	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D
Range of motion	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D
Ligament evaluation	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D
IKDC Final evaluation	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D	<input type="radio"/> A <input type="radio"/> B <input type="radio"/> C <input type="radio"/> D

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TEGNER ACTIVITY SCALE	
<p>10 Competitive sports soccer - national or international level</p> <p>9 Competitive sports soccer - lower divisions icehockey wrestling gymnastics</p> <p>8 Competitive sports bandy squash or badminton athletics (jumping, etc) downhill skiing</p> <p>7 Competitive sports athletics (running) motocross or speedway tennis handball or basketball Recreational sports soccer bandy or icehockey squash athletics (jumping) cross-country track findings (orientearing) both recreational and competitive</p> <p>6 Recreational sports tennis or badminton handball or basketball downhill skiing jogging at least 5 times weekly</p>	<p>5 Work heavy labour (eg building, forestry) Competitive sports cycling cross-country skiing Recreational sports jogging on uneven ground at least twice weekly</p> <p>4 Work moderately heavy work (eg lorry-driving, churning) Recreational sports cycling cross-country skiing jogging on even ground at least twice weekly</p> <p>3 Work light work (eg nursing) Competitive and recreational sports swimming walking in rough forest terrain</p> <p>2 Work light work walking on uneven ground</p> <p>1 Work sedentary work walking on even ground</p> <p>0 Sickleave or disability pension because of knee problems</p>
<p>Performed level</p> <p>Pre injury _____</p> <p>Prop _____</p> <p>Fp I _____</p> <p>Fp II _____</p> <p>Fp III _____</p> <p>Fp IV _____</p>	<p>Desired level</p> <p>Fp I _____</p> <p>Fp II _____</p> <p>Fp III _____</p> <p>Fp IV _____</p>

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LYSHOLM SCORE	
<p>Limp</p> <p>None 5 5 5 5 5</p> <p>Slight and/or periodical 3 3 3 3 3</p> <p>Severe and/or periodical 0 0 0 0 0</p> <p>Support</p> <p>None 5 5 5 5 5</p> <p>Stik or crutch 2 2 2 2 2</p> <p>Weight-bearing impossible 0 0 0 0 0</p> <p>Locking</p> <p>No locking and no catching 15 15 15 15 15</p> <p>Catching sensations but no locking 10 10 10 10 10</p> <p>Locking occasionally 6 6 6 6 6</p> <p>Locking frequently 2 2 2 2 2</p> <p>Locked joint on examination 0 0 0 0 0</p> <p>Instability</p> <p>No giving way 25 25 25 25 25</p> <p>Rarely, during athletics or other heavy exertion 20 20 20 20 20</p> <p>Frequently, during athletics or other heavy exertion (or unable to participate) 15 15 15 15 15</p> <p>Occasionally, in daily activities 10 10 10 10 10</p> <p>Often, in daily activities 5 5 5 5 5</p> <p>At every step 0 0 0 0 0</p>	<p>Pain</p> <p>None 25 25 25 25 25</p> <p>Inconstant and slight during heavy exertion 20 20 20 20 20</p> <p>Marked, during heavy exertion 15 15 15 15 15</p> <p>Marked, on or after walking >2 km 10 10 10 10 10</p> <p>Marked, on or after walking <2 km 5 5 5 5 5</p> <p>Constant 0 0 0 0 0</p> <p>Swelling</p> <p>None 10 10 10 10 10</p> <p>On heavy exertion 6 6 6 6 6</p> <p>On normal exertion 2 2 2 2 2</p> <p>Constant 0 0 0 0 0</p> <p>Stair-climbing</p> <p>No problems 10 10 10 10 10</p> <p>Slightly impaired 6 6 6 6 6</p> <p>One step at a time 2 2 2 2 2</p> <p>Impossible 0 0 0 0 0</p> <p>Squatting</p> <p>No problems 5 5 5 5 5</p> <p>Slightly impaired 4 4 4 4 4</p> <p>Not beyond 90° 2 2 2 2 2</p> <p>Impossible 0 0 0 0 0</p>
<p>Instability</p> <p>Prop _____ Fp I _____ Fp II _____ Fp III _____ Fp IV _____</p>	
<p>Pain</p> <p>Prop _____ Fp I _____ Fp II _____ Fp III _____ Fp IV _____</p>	
<p>Total</p> <p>Prop _____ Fp I _____ Fp II _____ Fp III _____ Fp IV _____</p>	
<p>Cause of additional surgery within 2 years</p> <p><input type="checkbox"/> No surgery <input type="checkbox"/> Flex def <input type="checkbox"/> Men probl <input type="checkbox"/> ACL-reinjury</p> <p><input type="checkbox"/> Ext def <input type="checkbox"/> Screw probl <input type="checkbox"/> Reinjury (other than ACL) <input type="checkbox"/> Other</p>	
<p>Patients evaluation at 2 years <input type="radio"/> Poor <input type="radio"/> Fair <input type="radio"/> Good <input type="radio"/> Excellent</p> <p>Patients expectancy at 2 years <input type="radio"/> Poor <input type="radio"/> Fair <input type="radio"/> Good <input type="radio"/> Excellent</p> <p>Observers evaluation at 2 years <input type="radio"/> Poor <input type="radio"/> Fair <input type="radio"/> Good <input type="radio"/> Excellent</p>	

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Figure 9.

A special protocol was developed for the pre-operative and/or post-operative clinical evaluations and was used in all studies.

Specific evaluation tools

IKDC evaluation system

The IKDC classification was based on the patients' subjective evaluation of their knee function, such as symptoms and activity level, as well as knee laxity and ROM examinations, which were performed by the independent examiner. The results were graded as A (normal), B (nearly normal), C (abnormal) or D (severely abnormal). The worst qualification within the subgroup produced the subgroup qualification and the worst subgroup qualification produced the final evaluation as described by Hefti and co-workers.⁷⁷ In the overall results, only the final IKDC classification was reported.

Lysholm knee-scoring scale

To avoid interviewer bias, the modified Lysholm knee-scoring scale was assessed by the patient using a self-administered questionnaire. The questionnaire did not show the scores for the alternative answers, as described by Höher and co-workers.⁸³ It consists of eight items, where pain and instability each account for 25 of the total score of 100 points.²²⁰

Tegner activity level

The Tegner activity level was assessed by the examiner during the course of the patient interview/examination. The score is graded between 0-10, where grades 0-4 cover activities of daily living and work and grades 5-10 indicate whether the patient is able to participate in recreational or competitive sports.²²⁰

Manual Lachman test

The manual Lachman test was estimated by the examiner as the amount of anterior drawer movement with the knee in 15°-20° of flexion. It was graded as 0, + (< 5 mm), ++ (5-10 mm) or +++ (> 10 mm), compared with the uninjured contralateral knee.²²³

Instrumented KT-1000 arthrometer test

The examination was standardised by always using the same bench and always having the patients in the supine position. Both legs were placed on a thigh support with 30° of knee flexion.⁷⁹ A foot-rest and a strap around the thighs kept the legs in a neutral position.^{56, 82} The arms were placed along the sides of the body and the patient was asked to relax (Fig. 10). The instrument was calibrated to zero before every displacement test. The AP displacement of the tibia in relation to the femur was registered at 20 pounds (89N) and at 30 pounds (134N). Firstly, the anterior displacement was registered and, subsequently, as the needle returned to zero, the posterior displacement was measured. The readings of the needle position were only accepted if the needle returned to zero \pm 0.5 mm when the tension in the handle was released.³⁸ In the literature, a side-to-side difference of > 3 mm in the anterior laxity measurement is defined as indicating an ACL injury.^{127, 215}



Figure 10.
The instrumented KT-1000 arthrometer test.
(Copyright Ninni Sernert)

Range of motion (ROM)

The measurement was performed in the supine position using a hand-held goniometer graded in one-degree increments. The patients first made an active full extension followed by an active full flexion.²⁷ The uninjured leg was always measured first and the side-to-side difference including hyperextension was calculated. If the measurements displayed a side-to-side difference of $\geq 5^\circ$ in either extension or flexion, the patients were categorically registered as having or not having an extension and/or flexion deficit.^{146, 204} The examiner always made a visual check to ensure that the measured side-to-side difference appeared reasonable.²⁷

One-leg-hop test

The one-leg-hop test was performed by jumping and landing on the same foot with the hands behind the back.⁷² (Fig. 11). Three attempts were made for each leg and the longest hop was registered for each leg separately. A quotient (%) between the index and uninjured leg was calculated.^{75, 221} Side-to-side symmetry of at least 85% is recommended before returning to sporting activities.^{13, 172}

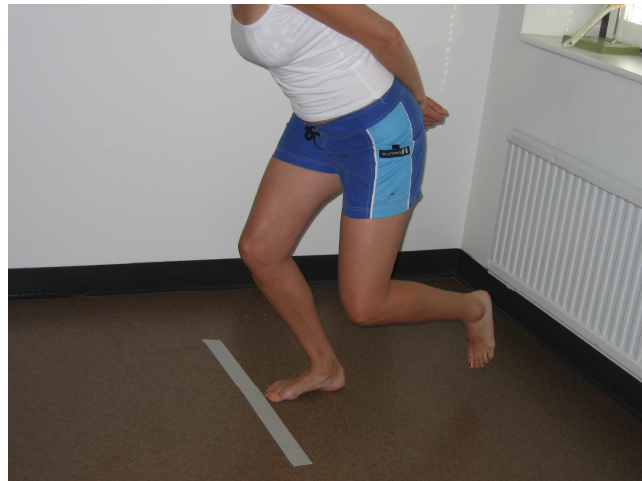


Figure 11.

The one-leg-hop test was performed by jumping and landing on the same foot with the hands behind the back. (Copyright Ninni Sernert)

Knee-walking test

The knee-walking test was used to assess the discomfort compared with the contralateral knee. The knee-walking test was performed on the floor of the examination room. The patients were not allowed to use any protection or clothing during the test. The patients knee-walked six steps forward and then subjectively graded the tests as OK (normal), unpleasant, difficult or impossible to perform, as described by Kartus and co-workers.^{99, 101} (Fig. 12).



Figure 12.

The knee-walking test was used in order to assess the discomfort compared with the contralateral knee. (Copyright Ninni Sernert)

Loss of skin sensitivity

The loss of or a disturbance in skin sensitivity was measured by the examiner palpating the anterior knee region. The length multiplied by the width was registered and the result is shown in cm^2 .^{99, 101} (Fig. 13).

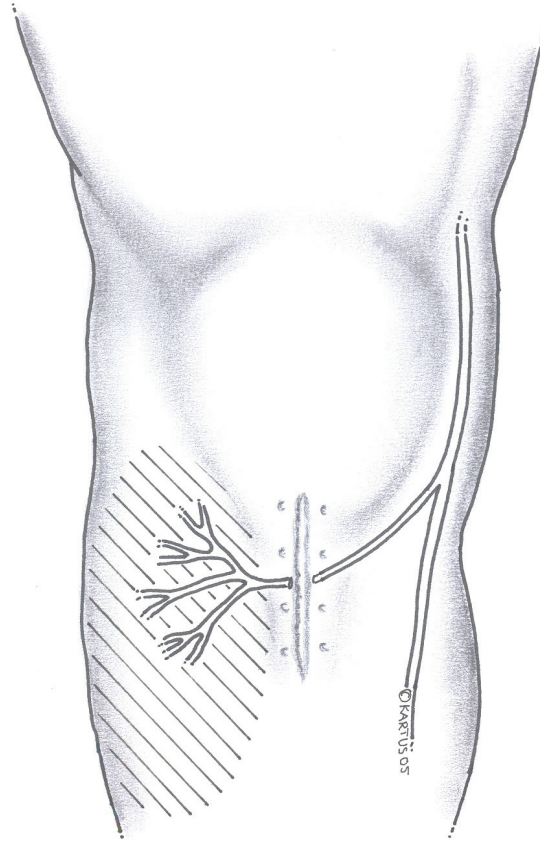


Figure 13.

The loss of or disturbance in skin sensitivity was measured by the examiner palpating the anterior knee region. (Copyright Catarina Kartus)

Guidelines for the rehabilitation programme

Using our rehabilitation guidelines, the local physiotherapists created an individual training programme. For the patients in *Studies II and III*, early weight-bearing was encouraged, as well as early full ROM training.^{89, 202} Closed kinetic-chain exercises were started during the first post-operative week.¹¹⁴ Strength training between 30-0° with an external load was not permitted during the first six post-operative weeks. Running was permitted after three months and contact sports at the earliest after six months, provided that the patients had regained functional strength and stability. For the patients in *Studies I and IV*, a knee brace in full range of motion was used for four weeks (range 3 to 6). Early range of motion training was encouraged, as well as early weight-bearing with crutches. Closed kinetic-chain exercises were started at three weeks. Return to sports was permitted after six months at the earliest, provided that the patients had regained functional strength and stability.

STATISTICAL METHODS

Study I

For the MRI measurements, mean (SD) values are presented. Median (range) values are presented for all other measurements. Wilcoxon's non-parametric test was used for comparisons over time, as well as for comparisons between the injured and uninjured side. A p-value of <0.05 was considered statistically significant.

Study II

Median (range) values are presented, except for the anterior KT-1000 arthrometer laxity measurements where mean (range) values are presented. Wilcoxon's signed rank test was used for comparisons of the pre-operative and post-operative data within the groups. The Mann-Whitney U-test was used to compare the variables between the groups. The chi-square test was used to compare dichotomous variables. A p-value of <0.05 was considered statistically significant. The primary variables in the study were the KT-1000 arthrometer laxity measurements and the anterior knee problems as measured with the knee-walking test. We expected a difference of at least one unit in the knee-walking test when planning the study. With a standard deviation of one unit in this test, a sample size of about 30 patients in each group estimates the power to over 90%. Correspondingly, a difference of 1.5 mm with a standard deviation of 2 mm in terms of the KT-1000 arthrometer measurements estimates the power to over 80%.

Study III

Median (range) values are presented, except for the anterior KT-1000 arthrometer laxity measurements where mean (range) values are presented. Wilcoxon's signed rank test was used for comparisons of the pre-operative and post-operative data within the study groups. The Mann-Whitney U-test was used to compare the variables between the groups. Fisher's exact test was used to compare dichotomous variables. Spearman's test was used for the correlation analyses. The intra-rater reproducibility analysis was performed using the kappa test. A p-value of <0.05 was considered statistically significant.

Study IV

Median (range) values are presented, unless a mean value is indicated. The Kruskal-Wallis test was used for comparisons between the three tendon specimen groups and the Mann-Whitney U-test was subsequently used for comparisons between the lateral and central index specimens and the control specimens. The chi-square test was used for comparisons of dichotomous variables. A p-value of <0.05 was considered statistically significant.

Ethics

The Human Ethics Committee at the University of Gothenburg approved all the studies in this thesis. All the patients gave their informed consent.

SUMMARY OF THE PAPERS

Study I: *The course of the patellar tendon after re-harvesting its central third for ACL revision surgery – a long-term clinical and radiographic study*

The hypothesis in *Study I* was that, in the long term, ACL revision surgery using re-harvested patellar tendon autografts would render a good clinical outcome and a normal patellar tendon at the donor site, as seen on MRI.

Patients and methods: Fourteen consecutive patients (5 females, 9 males) in need of ACL revision surgery underwent reconstruction using re-harvested patellar tendon autografts, see page 21. On both occasions, two and ten years after the index procedure, the clinical assessments involved the Tegner activity level, Lysholm knee-scoring scale, IKDC evaluation system, KT-1000 arthrometer laxity measurements, evaluation of disturbed anterior knee sensitivity, knee-walking ability and the one-leg-hop test. The MRI evaluations were performed on both knees on both occasions. Standard weight-bearing radiographic examinations in the AP and lateral views were classified according to the Ahlbäck and Fairbank rating systems. The surgical technique, the MRI evaluation and standard weight-bearing radiographic procedure are described on pages 24, 26 and 28.

Results: At the time of revision surgery, seven patients presented both lateral and medial meniscal injuries and four patients presented only a medial meniscus injury. Six patients presented mild degenerative changes in the knee. The serial MRI evaluations revealed that the thickness of the patellar tendon at the donor site was significantly increased compared with the non-harvested, normal contralateral side (Table 7) and that the donor-site gap was still visible after 10 years. No significant differences on the index side were seen between the two- and 10-year MRI evaluations (Table 8). Standard weight-bearing radiographic examinations revealed signs of mild degenerative changes in all patients. The clinical examination was performed on 14 patients at two years and 11 patients at 10 years. The results in terms of the Lysholm knee-scoring scale, IKDC evaluation system, one-leg-hop test, KT-1000 arthrometer laxity test and the knee-walking test revealed no significant differences between the two- and 10-year assessments. In overall terms, the clinical results were considered to be poor on both occasions. The Tegner activity level revealed no significant improvements between the pre-operative assessment and the two- and 10-year follow-ups.

TABLE 7: Serial MRI assessments of the patellar tendon, injured vs uninjured

	Injured	Uninjured	Significance (p-value)
Thickness at 2 years (mm ± SD)	6.4 ± 1.9	5.3 ± 1.2	n.s
Thickness at 10 years (mm ± SD)	6.4 ± 1.3	4.5 ± 1.3	0.017
Width at 2 years (mm ± SD)	33.1 ± 5.3	30.2 ± 3.8	0.047
Width at 10 years (mm ± SD)	32.5 ± 6.1	30.2 ± 4.1	n.s

A comparison with the normal uninjured contralateral side revealed a significant increase in thickness at 10 years, as seen on serial MRI assessments. Significant differences are presented in bold.

TABLE 8: Serial MRI assessments of the patellar tendon at the donor site

Measurements	2 years (n = 12)	10 years (n = 11)	Significance (p-value)
Donor-site gap (mm ± SD)	7.0 ± 3.5	5.7 ± 2.8	n.s
Thickness (mm ± SD)	6.4 ± 1.9	6.4 ± 1.3	n.s
Width (mm ± SD)	33.1 ± 5.3	32.5 ± 6.1	n.s

The serial MRI evaluations revealed that there were no significant differences between the two- and 10-year assessments in terms of donor-site gap, thickness and width. One patient was excluded from the assessment at 10 years due to metal artefacts. The same patient had suffered a patellar tendon rupture six months post-operatively.

Conclusion: MRI evaluation 10 years after ACL revision surgery using re-harvested patellar tendon autografts confirmed an abnormal patellar tendon at the donor site in terms of increased thickness and a visible gap. Assessments using standard weight-bearing radiographs revealed degenerative changes in all patients. No improvements in the clinical results were seen between the two- and 10-year follow-ups. The clinical results were regarded as poor on both occasions. The hypothesis was thus discarded.

Study II: *Patellar tendon or semitendinosus tendon autografts for anterior cruciate ligament reconstruction – a prospective randomised study with a seven-year follow-up*

The hypothesis in *Study II* was that, in the long term, ACL reconstruction using BPTB autografts would render more donor-site problems than ST autografts.

Patients and methods: Seventy-one patients with a symptomatic unilateral chronic ACL rupture were prospectively randomised for reconstruction using either an ipsilateral BPTB graft or an ipsilateral triple/quadruple ST graft, see page 21. In 34 patients, the central third of the patellar tendon was used as a graft (BPTB group) and, in 37 patients, the semitendinosus was used in the form of a triple (n=14) or quadruple (n=23) graft (ST group). The groups were comparable in terms of the pre-operative demographics. Pre- and post-operatively, the Lysholm knee-scoring scale, the Tegner activity level, the IKDC evaluation system, the KT-1000 anterior side-to-side difference, ROM, disturbances in sensitivity in the anterior knee region, kneeling discomfort, ability to knee-walk and the one-leg-hop test were assessed. The patients were rehabilitated according to a standardised protocol (see page 37). One surgeon with experience of using both techniques performed all the reconstructions. The surgical technique is described on pages 24-25.

Results: Sixty-eight (96%) of the patients were evaluated at 86 months (68-114). The prevalence of associated intra-articular injuries, such as meniscal ruptures, which were found or addressed at the index operation or during the follow-up period, were registered in 25/31 patients in the BPTB Group and 23/34 in the ST Group (n.s; p=0.23). At follow-up, no significant differences were found in terms of the Lysholm knee-scoring scale, Tegner activity level, the one-leg-hop test, KT-1000 anterior side-to-side difference, manual Lachman test, IKDC evaluation system, the ability to knee-walk, kneeling discomfort, ROM and disturbance in knee sensitivity. Both the BPTB Group and the ST Group improved significantly between the pre-operative assessment and follow-up in terms of most of the clinical assessments (Tables 9 and 10). No differences were found when comparing the post-operative ability to knee-walk and the prevalence of kneeling discomfort with the pre-operative values in both study groups.

Table 9.

	BPTB Group (n=34)	ST Group (n=37)	Significance BPTB v ST
Lysholm knee-scoring scale			
Pre-operative	70 (14-95) points	68 (21-100) points	n.s.
Seven-year follow-up	81 (25-100) points	90 (50-100) points	n.s.
Significance pre- v post-operative	p=0.001	p<0.0001	
Tegner activity level			
Pre-operative	3 (1-8)	4 (2-9)	n.s.
Seven-year follow-up	5 (0-7)	6 (2-9)	n.s.
Significance pre- v post-operative	p=0.001	p=0.0001	
IKDC at follow-up			
A (normal)	5 (16%)	6 (19%)	
B (nearly normal)	10 (32%)	10 (31%)	
C (abnormal)	9 (29%)	10 (31%)	
D (severely abnormal)	7 (23%)	6 (19%)	n.s.
KT-1000 anterior side-to-side difference			
Pre-operative at 89 N	4.5 (minus 7-20) mm	4.3 (minus 3.5-24.5) mm	n.s.
Seven-year follow-up at 89 N	1.7 (minus 5-6) mm	2.6 (minus 3.0-9.0) mm	n.s.
Seven-year follow-up at 134 N	2.3 (minus 3.5-9) mm	2.7 (minus 4.5-9.5) mm	n.s.
Significance pre- v post-operative at 89 N	p=0.004	n.s. (p=0.2)	
Manual Lachman test	(0) (+) (++) (+++)	(0) (+) (++) (+++)	
Pre-operative	0 2 9 19	0 7 17 10	p=0.006
Seven-year follow-up	8 21 1 0	7 23 1 1	n.s.
Significance pre- v post-operative	p<0.0001	p<0.0001	
One-leg-hop test			
Pre-operative	84 (0-111) %	81 (0-108) %	n.s.
Follow-up	96 (0-119) %	92 (0-110) %	n.s.
Significance pre- v post-operative	p=0.001	p=0.004	

Pre- and post-operative data in terms of the Lysholm knee-scoring scale, Tegner activity level and one-leg-hop test. Laxity assessments according to the KT-1000 arthrometer measurements and manual Lachman test and IKDC final evaluation pre-operatively and at follow-up in the BPTB Group and the ST Group. Significant values are presented in bold.

Table 10.

	BPTB Group (n=34)	ST Group (n=37)	Significance BPTB v ST
Knee-walking test			
Pre-operative			
Normal	42%	44%	
Unpleasant	39%	41%	
Difficult	13%	9%	
Impossible	6%	6%	n.s.
Follow-up			
Normal	39%	50%	
Unpleasant	26%	32%	
Difficult	16%	9%	
Impossible	19%	9%	n.s.
Significance pre- v post-operative	n.s. (p=0.1)	n.s. (p=1)	
Kneeling			
Pre-operative			
Normal	58%	71%	
Unpleasant	39%	24%	
Difficult	0%	3%	
Impossible	3%	3%	n.s.
Follow-up			
Normal	52%	59%	
Unpleasant	26%	35%	
Difficult	16%	0%	
Impossible	6%	6%	n.s.
Significance pre- v post-operative	n.s. (p=0.1)	n.s. (p=0.3)	
Disturbance in knee sensitivity (cm²)			
Pre-operative	0 (0-168)	0 (0-24)	n.s.
Follow-up	4 (0-299)	35 (0-282)	n.s.
Significance pre- v post-operative	p=0.01	p=0.0001	
ROM (range of motion)			
Pre-operative			
Extension	-5° (-15 - 10)	-5° (-20 - 5)	n.s.
Flexion	145° (90 – 150; mean 141 °)	145° (130 – 155; mean 145 °)	p=0.04
Follow-up			
Extension	-5° (-10 - 5)	-5° (-10 - 5)	n.s.
Flexion	140° (110 – 155; mean 140 °)	140° (130 – 155; mean 141°)	n.s.
Significance			
Extension pre-op versus follow-up	n.s. (p=0.5)	n.s. (p=0.4)	
Flexion pre-op versus follow-up	n.s. (p=0.2)	p=0.003	

Pre- and post-operative data in terms of knee-walking ability, kneeling ability, disturbance of anterior knee sensitivity and ROM in the BPTB Group and the ST Group. Significant values are presented in bold.

Conclusion: In general terms, the results are acceptable using both types of graft seven years after surgery. No clear advantage for either technique was demonstrated. Both techniques are reliable when it comes to improving patient performance, allowing a return to a higher level of activity than before surgery, and are therefore equally valid choices for ACL reconstructions even in the long term. Contrary to previous short-term studies, we found no significant differences in terms of donor-site morbidity and laxity between the study groups in the long term. The hypothesis was thus discarded.

Study III: *Osteoarthritic changes after Anterior Cruciate Ligament reconstruction using bone-patellar tendon-bone or hamstring tendon autografts – a retrospective seven-year follow-up study*

The hypothesis in *Study III* was that there is no difference in the prevalence of OA as seen in standard weight-bearing radiographic examinations, irrespective of the choice of graft in the long term, and that associated meniscal injuries will increase the prevalence of OA.

Patients and methods: One hundred and twenty-four patients suffering from a symptomatic unilateral ACL rupture were included in the study, see page 22. Seventy-two patients were reconstructed using ipsilateral BPTB autografts and 41 patients using either ipsilateral triple ST autografts or quadruple ST/G autografts. The surgical technique is described on pages 24-25. The patients were rehabilitated according to the same standard protocol (see page 37), including immediate full weight-bearing and full ROM. Radiographs were taken in the AP and lateral views and subsequently classified according to the Ahlbäck and the Fairbank rating systems (see page 28). Associated intra-articular injuries, such as meniscal ruptures, which were found or addressed at the index operation or during the follow-up period, were registered in 49/72 patients in the BPTB group and 31/41 in the HT group (n.s; $p=0.39$).

Results: The prevalence of OA as seen on standard radiographs was similar, irrespective of the choice of graft. In overall terms, 23% of the patients (BPTB 25%; HT 20%; n.s.) displayed OA changes according to the Ahlbäck rating system and 74% of the patients (BPTB 76%; HT 71%; n.s.) according to the Fairbank rating system. Patients with meniscal injuries, detected and treated before, during or after the reconstruction, had significantly more OA than patients without such injuries, when graded according to both the Ahlbäck and Fairbank evaluation systems. Furthermore, performing correlation analyses, older patients, as well as a longer time period from the injury to reconstruction, resulted in significantly more OA in terms of cumulative Fairbank changes. No difference in terms of the Tegner activity level, one-leg-hop test, IKDC evaluation system, manual Lachman test and the disturbed area of sensitivity was found between the BPTB and the HT Group. However, the Lysholm knee-scoring scale was significantly higher in the HT Group than in the BPTB Group. Furthermore, the knee-walking ability had deteriorated in the BPTB Group at follow-up. Both the BPTB and the HT Group improved in terms of the Lysholm knee-scoring scale, Tegner activity test, one-leg-hop test, KT-1000 anterior side-to-side difference and IKDC evaluation system.

Table 11.

	BPTB Group	HT Group	Significance
Ahlbäck medial	Grade 0: 82% (59/72) Grade 1: 17% (12/72) Grade 2: 0% Grade 3: 1% (1/74) Grade 4: 0% Grade 5: 0%	Grade 0: 83% (34/41) Grade 1: 15% (6/41) Grade 2: 0% Grade 3: 0% Grade 4: 2% (1/41) Grade 5: 0%	n.s. (p=0.9)
Ahlbäck lateral	Grade 0: 92% (66/72) Grade 1: 8% (6/74) Grade 2: 0% Grade 3: 0% Grade 4: 0% Grade 5: 0%	Grade 0: 93% (38/41) Grade 1: 5% (2/41) Grade 2: 0% Grade 3: 0% Grade 4: 2% (1/41) Grade 5: 0%	n.s. (p=0.9)

At seven years, the radiographic assessment revealed no significant difference between the BPTB Group and the HT Group with respect to OA changes according to the Ahlbäck rating system.

Table 12.

Fairbank	BPTB Group	HT Group	Significance
Flattening medial	54% (39/72)	46% (19/41)	n.s. (p=0.4)
Narrowing medial	39% (28/72)	26% (11/41)	n.s. (p=0.2)
Ridging medial	51% (37/72)	46% (19/41)	n.s. (p=0.6)
Flattening lateral	12.5% (9/72)	12% (5/41)	n.s. (p=0.96)
Narrowing lateral	11% (8/72)	12% (5/41)	n.s. (p=0.9)
Ridging lateral	33% (24/72)	34% (14/41)	n.s. (p=0.9)

113 patients underwent weight-bearing radiographs at follow-up and were classified according to the Fairbank rating system. The prevalence of degenerative changes was similar in the study groups.

Table 13.

	Meniscal injury	No meniscal injury	Significance
Ahlbäck medial	0 (0-5; mean 0.3)	0 (0-0; mean 0.0)	p=0.006
Ahlbäck lateral	0 (0-3; mean 0.1)	0 (0-1; mean 0.1)	n.s.
Cumulative Fairbank changes	2 (0-6; mean 2.1)	1 (0-4; mean 1.4)	p=0.03

Meniscal injuries were addressed before, at and after the index operation. Their influence on the prevalence of radiographically identified degenerative changes was statistically significant according to both the Ahlbäck (medial) and Fairbank classifications.

Conclusion: In this retrospective study, no difference in the prevalence of OA as seen on standard weight-bearing radiographs was found using either BPTB or HT autografts. In overall terms, the objective and subjective outcomes were comparable between the two groups. In patients with associated meniscal injuries, the prevalence of OA was higher. The hypothesis was thus verified.

Study IV: *A histological and ultrastructural evaluation of the patellar tendon ten years after re-harvesting its central third*

The hypothesis in *Study IV* was that, in the long term, the patellar tendon does not regain a normal histological and ultrastructural appearance after re-harvesting its central third.

Patients and methods: Twelve consecutive patients (4 females, 8 males) in need of ACL revision surgery underwent reconstruction using re-harvested ipsilateral central-third patellar tendon autografts, see page 23. Post-operatively the patients were rehabilitated according to a standardised protocol described on page 37. Biopsies were obtained from the patellar tendon 10 years after the ACL revision procedure and from the controls during primary ACL reconstruction using BPTB autografts. All the biopsies were evaluated with the aid of a light microscope and TEM. The surgical technique, biopsy procedure and the evaluation of the biopsy specimens are described on pages 24, 29 and 31.

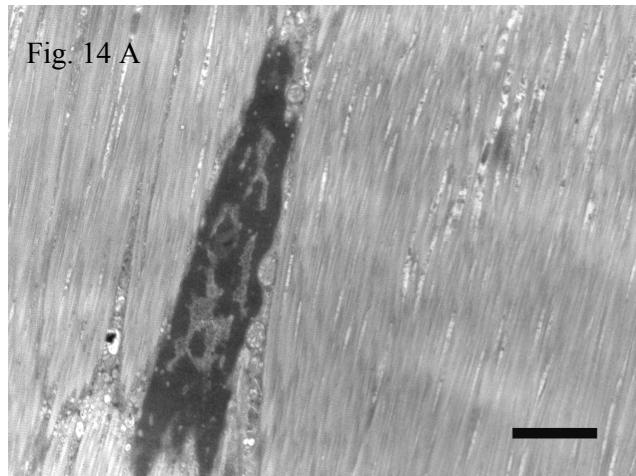
Histological results: The examination revealed that the fibre structure had deteriorated significantly in terms of its parallelness, as well as its mutual separation, and the cellularity and vascularity had increased significantly compared with normal tendon specimens. This was seen in biopsy specimens from both the re-harvested central part and the untouched lateral part of the tendon (Figs. 7 and 8). No significant differences were found between biopsy specimens obtained from the central and lateral parts of the tendon. No significant differences in the level of GAGs were detected between specimens from either part of the index tendon and the control specimens.

Ultrastructural results: Specimens from both the central and lateral parts displayed irregularities in the ECM, with collagen fibrils oriented in different directions, an increased amount of cell debris and more empty spaces between the fibrils compared with the normal tendon (Figs. 14 A-C). The relative distribution of the fibril diameter was different in the three groups. In the lateral and central parts of the index tendons, the two middle fibril size classes (31-60 nm and 61-90 nm) were most dominant when compared with the control specimens. In the specimens from the central part of the index tendons, the largest fibril size class was absent. The control biopsy presented the most heterogeneous fibril size distribution (Figs. 15 A-F).

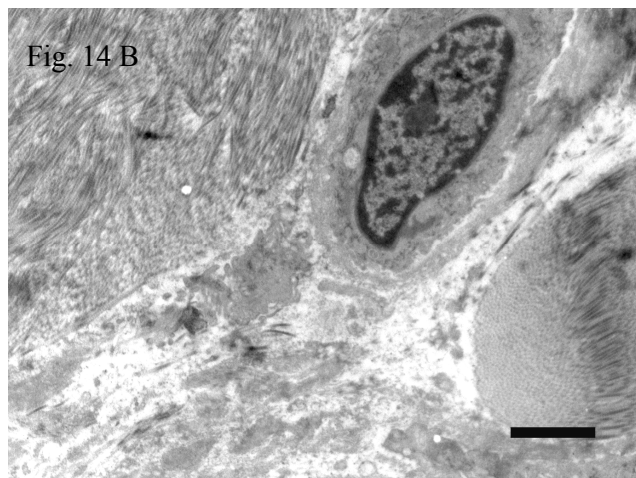
Conclusion: When re-harvesting the patellar tendon in ACL revision surgery, the donor site does not normalise in the long term in terms of its morphology. The patellar tendon has an abnormal histological and ultrastructural appearance, both in the central and in the peripheral part 10 years after re-harvesting its central third. The hypothesis was thus verified.

Figures 14 A-C.

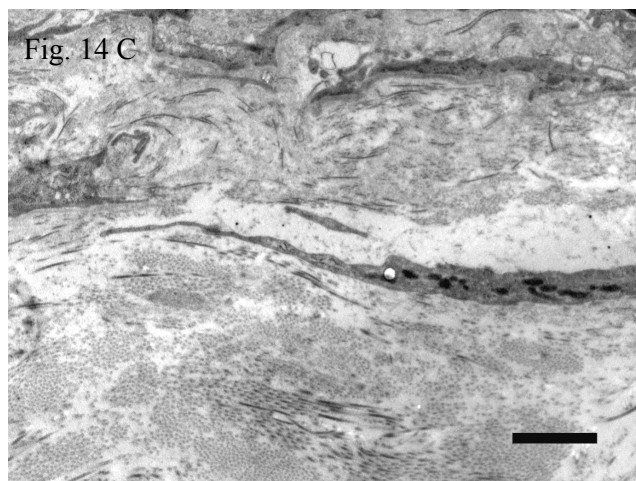
A. Transmission electron micrograph from a control specimen, showing a homogeneous ECM, where collagen fibrils are running in the same direction. The cells appear to have normal morphologic properties. Original magnification $\times 3000$. (With kind permission of SAGE publications)

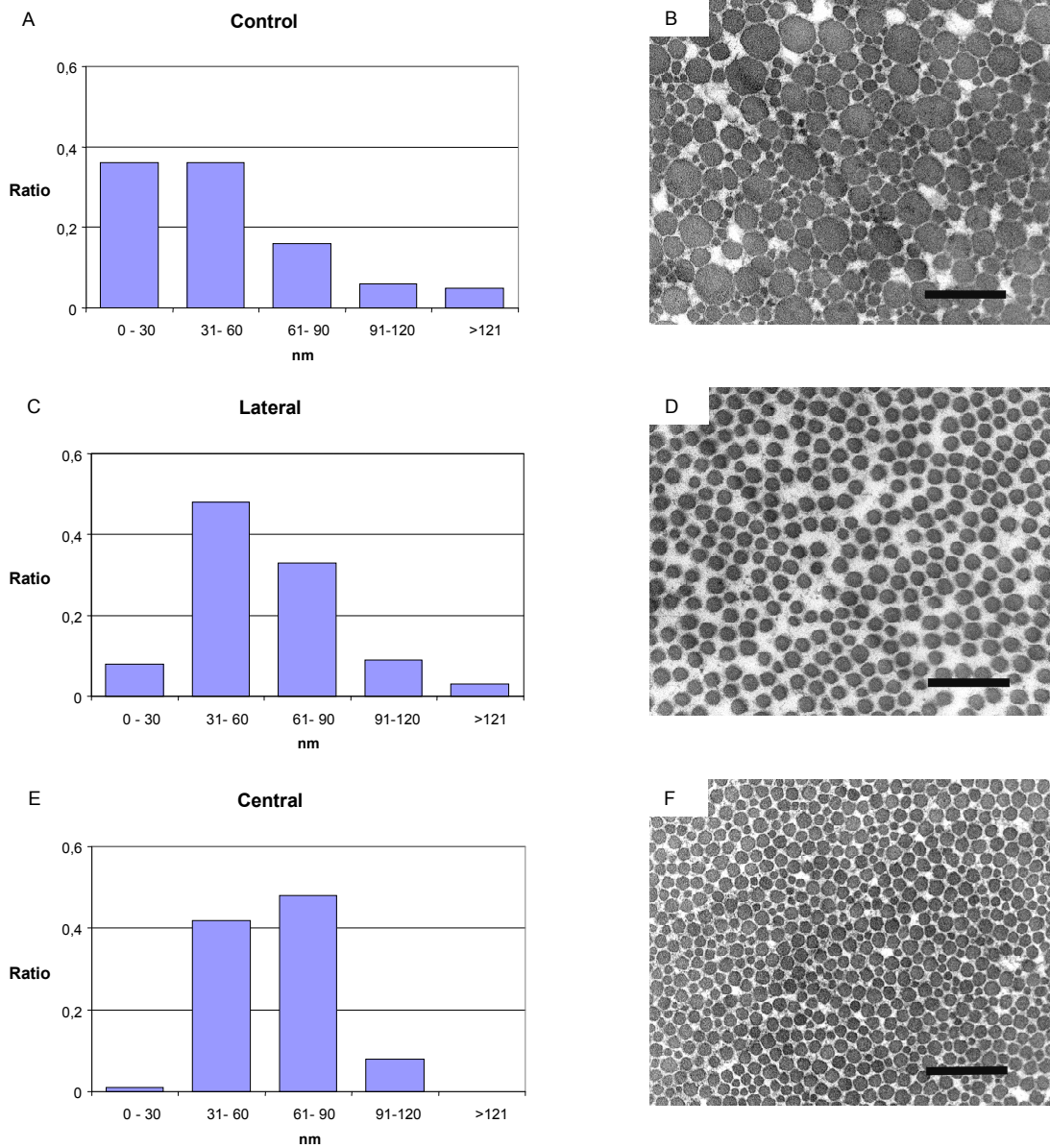


B. Transmission electron micrograph from a lateral specimen of a reharvested tendon showing collagen fibrils oriented in different directions. Furthermore, between the fibrils, cell debris and empty spaces can be seen. Original magnification $\times 3000$. (With kind permission of SAGE publications)



C. Transmission electron micrograph from a central specimen of a reharvested tendon showing fibrils oriented in different directions with empty spaces in between. Original magnification $\times 3000$. (With kind permission of SAGE publications)





Figures 15 A-F.

Relative distribution and transmission electron micrographs of the fibril diameter size in human patellar tendon from control biopsy specimens (A and B), lateral (C and D) and central (E and F) parts of the reharvested tendons. These figures show that there was a significant ($p < 0.0001$) difference in fibril size distribution between the groups. Bar = approximately $0.5 \mu\text{m}$. Original magnification $\times 101000$. (With kind permission of SAGE publications)

STRENGTHS AND LIMITATIONS

Study I

The strengths of *Study I* are its prospective design, repeated examinations and a median follow-up time of almost 10 years. Furthermore, the same surgeon performed all the revisions and the follow-up assessments were made by the same observer. To our knowledge, only a few reports on the results after ACL revision surgery using re-harvested ipsilateral patellar tendons can be found in the literature. Of these, none reports the long-term outcome.^{35, 102, 155, 162, 237}

The potential weaknesses of *Study I* are the lack of a control group and the fact that the previous ACL reconstruction involved the use of the medial third of the patellar tendon in six patients and the central third in eight patients. The number of patients is too small to justify an analysis of any differences between these two subgroups. One attractive alternative to re-harvesting the central third of the patellar tendon during ACL revision surgery is to use the HT autograft. It would have been of great interest to compare the clinical results after using re-harvested patellar tendon grafts with the use of a HT autograft, an allograft or even a synthetic graft in a controlled study. However, at the start of the present study, the use of HT autografts was not the procedure of choice at our institution.

Study II

The strengths of *Study II* are its prospective and randomised design, a follow-up rate of 96%, a power estimation of between 80 and 90% in terms of the primary variables, the fact that one surgeon experienced in both techniques performed all the reconstructions and that two independent observers, who were not involved in the surgery or rehabilitation, performed all the pre- and post-operative assessments. Apart from the use of a soft-threaded type of interference screw in the ST Group, the only variable that differed between the groups was the type of graft. All the other factors with an important impact on the final outcome, including the fixation technique and the rehabilitation protocol, were identical, thereby avoiding the bias of performance and detection.

The potential weaknesses of *Study II* involve the lack of radiographic assessments, as well as the fact that the KT-1000 anterior side-to-side difference was only measured at 89N pre-operatively and at 89N and 134N at follow-up. For comparisons with other studies, it might have been better to use the manual maximum test and to perform radiographic examinations. The bone-to-bone graft incorporation of the BPTB autograft is considered strong and reliable. However, concerns have been raised about the strength of the incorporation in the cancellous bone on both the femoral and the tibial side of the HT autograft using a 7 mm soft-threaded interference screw. At present, we are using a 9 mm interference screw on the tibial side.^{25, 110, 206} However, at the time of surgery, the 7 mm interference screw was the method of choice.

Study III

The strengths of *Study III* are the large number of patients, a follow-up period of seven years, the fact that the surgery was performed by one surgeon experienced in both methods and that the fixation of the grafts was made using the same method; i.e. interference screws. Two reproducible evaluation systems were used for the radiographic evaluation of the OA findings and an intra-rater reproducibility analysis was performed.

The limitation of *Study III* is its retrospective design. Although the patients underwent pre-operative clinical assessments, no radiographs were taken pre-operatively. However, the intra-articular damage seen arthroscopically was registered and revealed no significant difference between the study groups. It is possible yet unlikely that a longer follow-up period would reveal differences between the study groups that were not seen at seven years. One further possible weakness is the fact that the study was not designed to compare whether or not there was a difference in the development of OA between the study groups in the presence of meniscal damage. A subsequent subgroup analysis of this kind could not be justified. However, it seems unlikely that the choice of graft would matter in this respect. Similar concerns to those in *Study II* relating to the size of interference screw when using the HT autograft can be raised. The lack of power analysis in this retrospective study might also be a weakness. However, retrospective power analysis in terms of the Ahlbäck and Fairbank rating systems reveal powers of over 80%, with the present sizes of the study groups, an α -value of 0.05, expected differences of 1 unit between the study groups and an SD of 1.5 units.

Study IV

The strengths of *Study IV* are its long follow-up period of 10 years, the evaluation of both the histological and the ultrastructural appearance and the fact that it was performed on humans. The histological, morphological and ultrastructural appearance in humans after re-harvesting the patellar tendon has not been described previously.

One limitation of *Study IV* is that the control biopsies were obtained in an open fashion. However, in a study of the Achilles tendon, Movin and co-workers have shown that the specimens were categorised in a similar manner in the light microscope, regardless of whether the harvest was open or percutaneous.¹⁴⁴ In their study, the specimens were obtained in the same fashion as in the present study. Furthermore, in the present study, the tendon defect was left open, which might also be questioned. However, Brandsson and co-workers have shown the absence of any benefits when closing the patellar tendon defect after ACL ligament reconstruction.²⁶

Limitations of the methods

IKDC

The IKDC evaluation system was constructed as a “standardised international knee form” to make it possible to compare results after the treatment of knee injuries and, during the 1990s, it became the most widely used and accepted evaluation tool.⁷⁷ In the present thesis, the original IKDC form published in 1993 and revised in 1994 has been used. However, the committee envisaged a second, more comprehensive form, which was published in 2000. This instrument has been proven valid and reliable.^{87, 88} However, the decision to continue using the original system in this thesis was based on several reasons. A multitude of studies have been published using the original system, including all the previous studies from our research centre, rendering an opportunity for accurate comparisons over time. Furthermore, most of the patients in the present thesis have been evaluated before, making intra-individual comparisons possible.

KT-1000 arthrometer

The accurate measurement of AP laxity requires an objective instrumental assessment method. The KT-1000 arthrometer was developed to provide an objective measurement in the sagittal plane for the translation of the tibia relative to the femur.³⁸ It is currently the most frequently used arthrometer.⁴⁷ The reliability and reproducibility have been analysed by several authors.^{7, 179, 214, 239} Several arthrometers have been introduced and, when comparing five different arthrometers in 1992, Andersson and co-workers found that the KT-1000 arthrometer and the Stryker demonstrated the highest accuracy.⁷ However, several authors have questioned the usefulness of the KT-1000 arthrometer for diagnosing an ACL rupture in individuals.^{59, 92, 196}

Subjective evaluations

In recent years, researchers have focused more on assessments of the patient’s subjective evaluation than on the quantifiable results after surgery. Tests such as the WOMAC,¹⁵ ACL-QOL,¹³⁹ KOOS,¹⁸² SF-36¹⁹⁸ and EQ-5D⁶⁴ are more frequently used today than just a decade ago. These tests provide important information about the patient’s subjective experience. At the time when the studies in this thesis were planned, the use of the above scores was not as common as it is today. This is naturally a weakness of the studies included in this thesis.

GENERAL DISCUSSION

Revision ACL surgery

With increasing numbers of primary ACL reconstructions, the need for revision surgery due to both technical and traumatic graft failures will certainly also increase. If revision ACL reconstruction is used, the graft material is usually either an autogenous tendon graft other than the one used for primary reconstruction,⁶⁸ or a frozen allograft.¹⁵⁸ Re-harvesting autograft material that has already been used has been proposed in the literature.^{162, 241} Synthetic grafts are currently not recommended because of the high complication and failure rate.⁴⁶ Graft selection should be individualised depending on factors such as previous surgery, age, occupation and level of activity. Although there is a mixture of literature regarding revision ACL surgery, the outcomes, mainly reported in case series, appear to be inferior to those reported after primary ACL reconstructions.^{157, 186, 225, 232} A review by George and co-workers of the available English literature concludes that, in general, there is very little evidence regarding risk factors or prognosis following revision ACL surgery.⁶⁷ It is important to understand the causes of failure in order adequately to address the challenges of revision surgery.

In spite of reports from animal studies^{29, 116, 176, 192} and studies in humans^{14, 100, 120, 217} showing an abnormal histological and radiographic appearance after the primary harvest of the patellar tendon, re-harvesting the patellar tendon has been suggested as a graft option during ACL revision surgery. However, studies of the re-harvested patellar tendon as a graft in revision surgery, such as *Studies I* and *IV*, are sparse. Short-term results have been presented, but to our knowledge no reports on the long-term clinical outcome using re-harvested patellar tendon can be found in the literature.^{35, 102, 156, 162} Woods and co-workers reported good results in a follow-up after 43 months of 10 patients who had undergone revision surgery using the lateral third of the ipsilateral patellar tendon after the failure of a central-third graft.²³⁷ Since re-harvesting the patellar tendon is recommended by some authors, the long-term results are of special interest.^{35, 162, 237} In *Study I*, the clinical results at 10 years were considered poor. The Lysholm knee-scoring scale was a median of 60 points at two years and 58 points at ten years. Interestingly, the KT-1000 total side-to-side difference had diminished from 4 mm at two years to 2 mm at ten years, but this could be a result of the development of more degenerative changes over time. Comparisons with other studies are difficult to make since different outcome measurements are used. In a follow-up of 13 patients at 39 months after using re-harvested patellar tendon autografts, Colosimo and co-workers reported an average Tegner activity level of 5.8 and an average Lysholm knee-scoring scale of 77.6 points.³⁵ Noyes and co-workers reported results after ACL revision in 114 patients.¹⁵⁶ Eight of these represented re-harvested patellar tendon and three of these grafts failed. O'Shea and co-workers evaluated eight

patients two years after revision ACL reconstruction using re-harvested patellar tendon autografts.¹⁶² The KT 1000 side-to-side difference in their study was 1.6 ± 1.2 mm.

Technical errors at primary reconstruction and re-injury are regarded as the most common causes of failure.^{102, 203, 219} The incidence of graft ruptures after ACL revision surgery in general and after re-harvesting the patellar tendon in particular is unknown.

There are some reports in the literature on patellar tendon ruptures and patellar fractures after ACL primary reconstruction using patellar tendon autografts.^{23, 24, 41, 115, 130, 138, 142, 165} Christen and Jakob found three patellar fractures in a follow-up of 490 patients after using central-third patellar tendon autografts in ACL reconstruction.³⁴ Since biomechanical analysis of the re-harvested patellar tendon in animal studies reveals reduced strength and stiffness, the risk of re-ruptures should theoretically be increased.^{29, 116} However, in *Study I*, one patellar tendon rupture and one patellar fracture in 14 patients must be regarded as a relatively large number of serious complications. One patient suffered a dislocated patellar fracture when slipping on the street two weeks after revision surgery and one patient suffered a patellar tendon rupture six months post-operatively due to hyperflexion of the knee after a falling accident. A test of the tensile strength of the patellar tendon 10 years after re-harvesting its central third would have been interesting, but for obvious reasons this is impossible to perform in a study of humans, as long as non-invasive techniques are not available. After primary ACL reconstruction, Salmon and co-workers found 12% new ACL ruptures (6% ipsilateral graft and 6% contralateral knee) among 675 patients using BPTB or HT autografts with a mean follow-up of five years.¹⁸⁸ Furthermore, twelve months after reconstruction, they found that the ACL graft was at no greater risk of re-rupture than the contralateral knee. Due to the poor clinical results and the high frequency of major complications, the main message of *Study I* is that re-harvested patellar tendon autograft is an inferior graft option for ACL revision surgery.

MRI

The principal finding in *Study I* was that the patellar tendon, as seen using MRI examinations, did not regain a normal morphological appearance of the donor site, up to ten years after the re-harvesting procedure. Three parameters were examined; the thickness, width and size of the central donor-site gap of the patellar tendon. We did not measure the length of the patellar tendon, after re-harvesting the BPTB graft with adjacent bone blocks from the patella and tibial tubercle, as there are obvious difficulties when it comes to finding reliable bony landmarks to measure between the proximal tibia and patella. RSA appears to be a more reliable method than MRI for this type of measurement. Adam and co-workers reported on ten consecutive patients, in whom the central third of the patellar tendon was used to

reconstruct the ACL.¹ A decrease in the length of the patellar tendon was observed in all cases using the RSA technique, twelve months after the harvesting procedure. However, the shortening process only continued until the twelfth post-operative week, after which no further shortening occurred. After re-harvesting the patellar tendon, the risk of shortening appears to be even greater than after primary harvest. It would have been interesting to measure the length of the patellar tendon in a reliable way.

Our hypothesis in *Study I*, that the patellar tendon at the donor site would appear normal or close to normal, could not be verified 10 years after re-harvesting its central third. The serial MRI evaluations revealed that, at 10 years, the gap was still present in 10 of 11 patients and, compared with the normal contralateral side, the thickness had significantly increased at 10 years.

Some authors have reported that the patellar tendon does not normalise radiographically after primary harvest of its central third.^{98, 100, 120} Recently, Svensson and co-workers presented the first long-term serial MRI study of the donor site after primary harvest of the central third BPTB autograft.²¹⁷ Their study revealed that the thickness of the remaining patellar tendon increased compared with the healthy contralateral side until two years after the index operation and then decreased to resemble the normal thickness at six years. The width increased regardless of the time, whereas the donor-site gap decreased over time. However, at six years, the gap was still found in some of the patients. Contrary to these findings, Berg and co-workers and Nixon and co-workers have shown in short-term studies after primary harvest that the harvest-site defect was indistinguishable from normal tendon as seen on MRI.^{16, 153} Similarly, Coupens and co-workers speculate that the patellar tendon regenerates and re-models post-operatively, because of MRI findings indicating a decrease in oedema and scar tissue until 18 months, when the tendon appeared normal.³⁷ Meisterling and co-workers described near-normal width and thickness two years after the primary harvest of the central third of the patellar tendon.¹³⁵ Correspondingly, Bernicker and co-workers found that the patellar tendon had started to reconstitute itself one year after ACL reconstruction, but there was still a significant gap.¹⁷ To our knowledge, no other long-term MRI studies of the patellar tendon after re-harvesting its central third are available in the literature.

It appears that *Study I*, as well as previous studies in the literature, indicates that a re-modelling process continues for years after the harvesting procedure. It also appears that the healing and adaptation of the patellar tendon is a very slow process. The macroscopic appearance as seen using MRI had not normalised 10 years after the re-harvesting procedure, but these findings did not provide any information about the histological or ultrastructural factors that might explain this process. We are aware of the fact that MRI does not describe the quality of the

tissue in the tendon or the gap in the tendon and additional studies investigating the ultrastructure and the histological appearance therefore appear to be necessary.

Animal studies have shown a reduction in strength of approximately 30-50% in both the remaining two thirds and the re-harvested central third of the patellar tendon.^{20, 29, 116, 192} In contrast, Linder and co-workers have reported no differences between the strength and stiffness of the index and the control side in dogs three and six months after harvesting the medial third of the patellar tendon.¹¹⁹ *Study IV* is therefore important to further analyse the course of the patellar tendon after re-harvesting its central third.

Histological aspects

In the literature, only a few studies of patellar tendon donor-site histology after harvesting its central third in humans are presented and, to our knowledge, there are none reporting the tendon response to repeated surgical trauma.^{16, 100, 153, 216} Frank and co-workers described the healing process of normal ligaments in rabbits after repair.⁶⁰⁻⁶² After a brief period of haemorrhage and inflammation and a subsequent period of proliferation, there was a prolonged phase of re-modelling that required up to 2.5 years to be complete. Initially, there was an accumulation of inflammatory cells and fibroblasts in a disorganised fashion, with vascular channels cutting through the hypercellular scar. As time progressed, the number of cells decreased and became more elongated and oriented in the longitudinal axis of the ligament. Using light and electron microscopy, Battlehner and co-workers¹⁴ found that the patellar tendon did not regain the appearance of normal tendon, a minimum of two years after ACL reconstruction using primary harvested central-third patellar tendon autografts and closing the defect. Kartus and co-workers, as well as Svensson and co-workers, reported abnormal tissue composition as seen in the light microscope in both the central and the peripheral parts of the patellar tendon after primary harvest and leaving the defect open after two and six years respectively.^{100, 216} In contrast, Nixon and co-workers found tissue that was indistinguishable from normal tendon using light microscopy two years after primary harvest of the central third of the patellar tendon and leaving the defect open.¹⁵³ Berg and co-workers found that the primary harvest-site defect was filled with hypertrophic tendinous tissue eight months after harvesting its central third and leaving the defect open.¹⁶

Performing biopsies on the patellar tendon after revision ACL surgery appears to offer a unique opportunity to analyse and assess the tendon response to repeated trauma. In *Study IV*, four parameters were examined: fibre structure, cellularity, vascularity and level of GAGs. The examination revealed that the fibre structure had deteriorated significantly in terms of its parallelness, as well as its mutual separation, and that the cellularity and vascularity had increased significantly compared with normal tendon specimens. This was seen in biopsy specimens from

both the central and peripheral parts of the tendon. No significant differences were found between biopsy specimens obtained from the central and lateral parts of the tendon. Nor were any significant differences in the level of GAGs detected between specimens from either part of the tendon and the control specimens.

GAGs generally appear in low concentrations in the normal patellar tendon.^{5, 6} An increased GAG concentration is found in Achilles tendinopathy,¹⁴³ in patellar tendinosis in jumper's knee,¹⁰⁷ in tendons subjected to compression forces²³³ and in ruptured tendons compared with healthy tendons.⁹⁵ However, we found no disparity in the GAG content between the re-harvested tendon specimens and the control specimens, indicating that the repair tissue does not display similarities with the degenerative tendon pathology seen in achillodynia and jumper's knee. One possibility, however, is that staining with Alcian Blue (pH 2.5)/Periodic Acid-Schiff (AB/PAS), as in the present study, is not sensitive enough to detect small differences with low levels of GAGs. On the other hand, there are similarities between the findings in the present study and the results of histological studies of symptomatic tendinopathies describing changes in fibre structure, variations in cellularity, increased vascularity and increased amounts of ECM debris. However, the non-inflammatory reactive process that is visible in tendinosis includes an increased amount of GAGs, which we were unable to verify in the present study.^{10, 107, 143}

The fact that the histological changes were found not only in the central specimens, where a surgical trauma had taken place, but also in the peripheral specimens, which were not primarily affected by surgery, is of particular interest. It appears that, by harvesting and re-harvesting the central third of the patellar tendon, a histological situation is created and it continues to affect the entire tendon 10 years after surgery.

Ultrastructural aspects

In *Study IV*, we focused on the ultrastructural appearance of the re-harvested patellar tendon. To the best of our knowledge, there are no studies in the literature reporting either the histological or the ultrastructural appearance after re-harvesting the central third of the patellar tendon, not even in the short term. The ultrastructural appearance of the normal healthy patellar tendon has previously been described by Svensson and co-workers.²¹⁸ The ECM is compact, with the collagen fibrils regularly oriented along the long axis. The cell density and shape of the tenocytes vary from flattened to swollen and no cell debris is present.

Ultrastructurally, the patellar tendon appears to react in a similar way to several different situations, such as surgical trauma or change of load. In animal models, the collagen fibril diameter in the patellar tendon has been found to decrease in response to stress shielding,^{126, 145} when subjected to high stress levels,¹⁶⁷ with

ageing^{43, 148} and disuse.¹⁴⁹ Furthermore, in humans, a focal loss of larger collagen fibrils has been found in ruptured Achilles tendons at the rupture site,¹²⁵ as well as in elderly persons.²²⁴ On the other hand, it has been shown in animals that an increase in physical activity may reduce or^{137, 169} increase¹³⁷ the fibril size or even leave it unchanged.¹⁶⁸

Svensson and co-workers assessed the patellar tendon six years after primary harvest during ACL reconstruction and found that the patellar tendon had not recovered a normal ultrastructure either in the central or in the peripheral part, as seen using TEM.²¹⁸ In some of the specimens, the collagen fibrils were oriented in different directions and areas containing cell debris were found. The relative distribution of the fibril diameter was different compared with the normal tendon, in that fibrils with smaller diameters dominated. In *Study IV*, 10 years after re-harvest, a similar picture was revealed. Forty-two per cent of the specimens from the lateral part of the re-harvested patellar tendon displayed a close to normal morphology, whereas 58% of the specimens showed a more pathological morphology. The fibrils were oriented in an unparallel manner, cell debris was present and the density of the tenocytes was decreased. In specimens from the central part of the patellar tendon, a similar pathological morphology was found in 50% of the biopsies.

The distribution of fibrils in specimens from the re-harvested patellar tendon differed from the control tendons in *Study IV*. In the re-harvested specimens from both the lateral and the central parts of the patellar tendon, the medium-sized fibrils dominated (31-90 nm). This is not entirely in line with the findings of Svensson and co-workers, because fibrils with a smaller diameter dominated in their material.²¹⁸ However, when looking closely at their material a similar significant dominance of fibrils sized 31-60 nm is revealed. In *Study IV*, the largest ratio of large diameter fibrils was found in the control specimens. It is within the large fibrils that the largest cross-sectional area of collagen is present and this is where the high tensile strength of the patellar tendon is thought to reside,¹⁶⁷ indicating inferior tensile strength in the re-harvested patellar tendon. The somewhat lower frequency of the smallest fibrils in *Study IV*, compared with the study by Svensson and co-workers might indicate an ongoing maturation process, considering that the time period between harvest and the biopsy procedure was almost twice as long as the period Svensson and co-workers reported in their study.²¹⁸

An extended evaluation of the re-harvested patellar tendon, involving an assessment of the presence of hypoxic degenerative tendinopathy, mucoid degeneration, tendolipomatosis and calcifying tendinopathy as seen on electron microscopy in degenerative tendons, would have been valuable, but no such evaluation was performed in *Study IV*.⁹⁵ TGF- β 1 is a cytokine responsible for the recruitment and proliferation of fibroblasts and macrophages, as well as the

regulation of enzymes and angiogenesis. It is therefore associated with the formation of scar tissue following injury. Similarly, bFGF (Fibroblast Growth Factor) has been shown to be both a powerful stimulator of angiogenesis and a regulator of cell proliferation. The increased expression of these molecules is a characteristic of the fibrotic healing of tendons after injury.⁵² Testing for biochemical markers, such as growth factors, or collagen cross-linkage therefore adds information about the re-modelling process. In *Study IV*, interest focused primarily on the fibrils, the ECM and the tenocytes and the lack of an extended evaluation could naturally be regarded as a weakness of the study.

Graft selection

At present, the commonly used grafts for ACL reconstructions are the BPTB and HT autografts. Several prospective, randomised studies comparing the outcome up to two years have been published.^{2, 8, 19, 48, 49, 53, 91, 128, 161, 197} However, studies comparing the results after five years or more are sparse.^{84, 131, 187} In *Study II*, which was prospective and randomised, the follow-up was seven years and the follow-up rate was 96%. In the five-year follow-ups by Matsumoto and co-workers and Sajovic and co-workers, the follow-up rate was 90% and 85% respectively.^{131, 187} In the seven-year follow-up which exclusively comprised males by Ibrahim and co-workers, 77% attended the follow-up.⁸⁴ No power estimations were made at the start of the above-mentioned studies.

The evaluation of the objective and subjective outcomes in *Study II* revealed acceptable results in terms of the Lysholm knee-scoring scale, Tegner activity level and IKDC evaluation system. The results were generally in line with or slightly inferior to the results in the studies by Ibrahim and co-workers, Matsumoto and co-workers and Sajovic and co-workers.^{84, 131, 187} In *Study II*, no significant differences between the BPTB Group and the ST Group in terms of the functional outcome were detected. In the long term, in the above studies, no significant differences between the study groups were found, except that, in the study by Ibrahim and co-workers, the patients who underwent reconstruction using BPTB autografts had more patello-femoral problems and loss of motion and, in the study by Matsumoto and co-workers, patients in the HT Group had fewer problems at the graft harvest site.^{84, 131} The reduced difference in donor-site morbidity between the BPTB and the HT autografts at seven years in *Study II* may have been caused by sensory nerve adaptation in the prepatellar region. Furthermore, the development of disturbing degenerative changes over time might eventually be more important than initial short-term donor-site symptoms. On the other hand, it might also be the case that this finding is actually a type II error, i.e. the study groups were too small.

Development of osteoarthritis in the long term after ACL reconstruction

The incidence and progression of OA following ACL injury have not been clearly demonstrated. Patients with chronic ACL deficiency run an increased risk of secondary meniscal damage.^{39, 90} In one study, 80% of the patients were found to have a torn meniscus within two years of ACL injury.¹⁶⁴ Meniscectomy, together with an ACL injury, is generally believed to cause OA.^{54, 70, 93, 136, 201, 240} In *Study III*, the presence of meniscal injuries increased the prevalence of OA. Nebelung and co-workers found that 35 years after a conservatively treated ACL injury, 95% of 19 athletes had meniscal and cartilage damage. In 10 of the knees, a total knee replacement had been performed and, in one additional case, a total knee replacement was strongly suggested.¹⁵⁰ However, the value of ACL reconstruction in an ACL-deficient knee in preventing the development of OA has not been substantiated and the development of OA using different grafts remains unclear.¹²³ The prevalence of OA when using the BPTB autograft has been studied by Jomha and co-workers, Shelbourne and co-workers and Seon and co-workers.^{93, 195, 200} The prevalence of OA was 55%, 11% and 43% at 7, 4 and 11 years respectively. Part of this difference can be explained by the use of different evaluation systems. The overall prevalence of OA in *Study III* was 23% according to the Ahlbäck rating system and 74% according to the Fairbank rating system, thus demonstrating the impact of using different grading systems. Furthermore, in *Study III*, no significant differences were evident when comparing the radiographic outcome of BPTB and HT autografts. The findings in *Study III* are consistent with the radiographic findings at five years reported by Harilainen and co-workers in their randomised, prospective study.⁷⁴ Contrary to the findings in *Study III* and the findings reported by Harilainen and co-workers, the patients with BPTB autografts had a higher incidence of OA than patients with HT grafts in the studies by Roe and co-workers, Sajovic and co-workers and Pinczewski and co-workers.^{174, 181, 187} These authors have proposed a difference in knee kinematics with the various graft types. However, Chouliaras and co-workers found no difference in either AP laxity or tibial rotation after using different autografts, using an advanced six-camera optoelectronic system while the subjects descended stairs and, immediately after, pivoted on their leg of landing.³³ The most reliable and accurate method for estimating knee kinematics would be the RSA technique. To date, we do not know of any study using this method for comparisons of the results after using the BPTB and the HT autograft. The follow-up time was seven years in *Study III*. The development of OA is a slow process and the objection can be made that seven years is too short a period to reveal differences between the graft types. However, in the studies previously mentioned, the follow-up times varied from five to 10 years. We therefore feel that seven years should be long enough to reveal considerable differences between the two different autografts. In a study by Seon and co-workers, an interval of more than six months from injury to reconstruction affected the prevalence of OA.¹⁹⁵ In *Study III*, there was a slight, yet significant

correlation between the time from injury to reconstruction, which varied between two and 360 months, and the cumulative Fairbank changes. To our knowledge, the impact of time between the injury and surgery on the development of OA has not previously been reported in the literature. However, since this correlation was a subsequent not initially planned analysis in *Study III*, the conclusions have to be verified in other studies. However, as mentioned previously, an increase in the prevalence of meniscal injuries increases the prevalence of OA and, in the literature, there is evidence that meniscal injuries are more frequent when the reconstruction is delayed.⁹⁶ Important features of *Study III* are that there were no significant differences between the two grafts in terms of degenerative changes and meniscal injuries before or at the reconstruction or during the follow-up period.

Two patients (2.8%) in *Study II* and three patients (2.4%) in *Study III* suffered clinical signs of bacterial arthritis. The reported incidence rate in the literature is between 0.14% and 0.78%.^{22, 85, 94, 132, 231} Previous knee surgery is found to be associated with post-operative infections.¹³² During the initial phase of a joint infection, many bacteria produce proteolytic enzymes, such as collagenase, that directly destroy the cartilage.⁸⁰ Furthermore, a substantial part of the articulate damage results from the attempts by the immune system to eradicate the infection, particularly by producing chondrodestructive cytokines such as IL-1 and TNF- α .⁸⁰ Immediate antibiotic administration is important to prevent cartilage degradation.²⁰⁹ Indelli and co-workers stated that the goal of treatment for septic arthritis after ACL reconstruction is firstly to protect the articulate cartilage and secondly to protect the graft.⁸⁵ In *Studies II* and *III*, the patients who developed septic arthritis all healed uneventfully after arthroscopic lavage and the administration of intravenous antibiotics.

Taken together, the most important finding in *Study III* is that the presence of meniscal injury increased the prevalence of OA in the long term.

CONCLUSIONS

- The long-term clinical results after ACL-revision surgery using re-harvested ipsilateral central-third patellar tendon autografts are poor.
- In the long term, MRI reveals an abnormal donor site in terms of increased thickness and a visible gap after ACL-revision surgery using ipsilateral re-harvested central-third patellar tendon autografts.
- Standard weight-bearing radiographs reveal degenerative changes in all patients ten years after revision surgery, using re-harvested ipsilateral central-third patellar tendon autografts.
- Seven years after primary ACL reconstruction, the subjective and objective outcomes were similar and acceptable after using central-third, BPTB autografts and triple/quadruple ST autografts. No clear advantage for either technique was demonstrated.
- There were no significant differences in terms of donor-site morbidity and laxity between the study groups seven years after primary ACL reconstruction using either BPTB autografts or ST autografts.
- At a median of seven years after primary ACL reconstruction using either BPTB or HT autografts, the prevalence of OA as seen on standard weight-bearing radiographs and the clinical outcome were similar.
- The presence of meniscal injuries increased the prevalence of OA seven years after primary ACL reconstruction using either BPTB or HT autografts.
- The patellar tendon does not regain its normal histological and ultrastructural appearance in the long term, either in the central or in the peripheral part, after re-harvesting its central third in revision ACL surgery.

CLINICAL RELEVANCE

The findings in *Studies I* and *IV* that radiographic, histological and ultrastructural evaluations of the patellar tendon in the long term after re-harvesting its central third revealed abnormalities are indicating that the tendon will never normalise. These findings also indirectly indicate that the quality of the tendon tissue is inferior compared with that of normal tendon. Furthermore, the clinical results were considered poor. Re-harvesting the central third of the patellar tendon for use as a graft in the event of ACL revision surgery can therefore not be recommended.

Study II revealed acceptable objective and subjective results after using either the BPTB or the HT autograft for ACL reconstruction. Both grafts can therefore be considered reliable with no clear advantage for either technique. At seven years, there were no significant differences in terms of donor-site morbidity and laxity between the study groups. *Study III* revealed that the prevalence of OA, as seen on standard weight-bearing radiographs, for the BPTB and HT autograft at seven years was comparable. The grafts are therefore equally valid choices for ACL reconstructions even in the long term in terms of the development of OA.

FINAL CONSIDERATIONS AND THE FUTURE

In this thesis, the findings and problems that can occur in patients who require primary or revision ACL surgery are discussed. The donor site at the patellar tendon, after re-harvesting its central third, has been thoroughly examined clinically, radiographically, histologically and ultrastructurally. All the different evaluation methods indicate that the patellar tendon probably never normalises after re-harvesting its central third. The findings in the study can be used as a model for what happens in the long term when a tendon is subjected to repeated surgical trauma.

In recent years, the “gold standard” for ACL reconstruction, the BPTB autograft, has gradually been replaced by the HT autograft. The change has taken place with only weak or no scientific proof. Gradually, however, research is starting to support this change, as more prospective, randomised trials comparing BPTB and hamstring tendon autografts have been published during the last decade.^{2, 19, 45, 48, 53, 84, 128, 131, 187} According to these studies, the HT graft appears to have advantages compared with the BPTB autograft, mainly in terms of less donor-site morbidity in the short term. This opinion is further supported by the reported capacity of the HT tendon to regenerate.^{50, 55, 166} In the long term, however, these advantages appear to diminish. Evaluating the HT as thoroughly as the patellar tendon was evaluated in the present study appears to be an interesting perspective for future research. The importance of meniscal injuries in the ACL-reconstructed knee for the development of OA is indisputable. Future studies with a prospective design should be able to answer the question about the best way to address these injuries.

Refining the present techniques might produce further improvement potential in ACL reconstructive surgery. Can stimulating growth factors improve the healing of the graft to its fixation sites? Is there any advantage in using HT autografts from the contralateral side? Is the so-called delayed reconstruction the optimal timing for surgery?⁵⁸ Which is the ideal graft of the future? Is it one of the autografts already in use, an allograft or could it even be a cultured ligament?¹⁷¹ A synthetic ligament with properties similar to the autografts used at the present time would probably challenge these completely. Will we be able to manufacture such synthetic grafts? Could a direct suture of the injured ligament augmented with periosteum or some kind of allograft have a second chance? What about the results after ACL reconstruction using the double-tunnel technique? Involving histological and ultrastructural aspects in all these questions could create ideas for numerous future projects.

The choice of a proper graft in revision surgery results in additional considerations. The complexity of repeated surgery has to be illuminated. Further insight into the complexity and biology of donor-site morbidity is needed. What is the role of

damage to the infrapatellar nerve and the subsequent formation of neuroma? How do we prevent failures such as re-ruptures? Biomechanical analysis of the ACL and the ACL-reconstructed knee has traditionally been evaluated in cadaver studies. The results of these studies are useful; however, their application can be limited without information about their behaviour in vivo. Measuring the strength of the tendon in living humans is impossible for obvious reasons. Will there be another methodology that can answer these questions? The multi-centre or even national registration of all patients undergoing ACL reconstructions and ACL revisions would be of great interest. In 2005, a national ACL register was introduced in Sweden. It will provide an opportunity to answer some of the questions associated with surgically treated ACL injuries.

Långtidsuppföljning efter rekonstruktion och revision av främre korsbandet med tonvikt på det kliniska, radiologiska, histologiska och ultrastrukturella resultatet.

**Mattias Lidén
Göteborg 2008**

Studiens syfte var att genomföra en analys av det kliniska, radiologiska, histologiska och ultrastrukturella mönstret efter återskördning av knäskålsens centrala tredjedel vid korsbandsrevisionskirurgi. Knäskålsenan undersöktes tio år efter korsbandsrevision och jämfördes med frisk kontrollsenan. Dessutom var syftet med studien att jämföra långtidsresultatet efter primär korsbandsrekonstruktion med knäskålssnegraft (BPTB) eller hamstringsnegraft (HT).

Samtliga patienter rehabiliterades enligt ett standardiserat protokoll där full rörelseträning tilläts omedelbart postoperativt. De primärt rekonstruerade patienterna fick belasta fullt omedelbart efter operation, medan de reviderade patienterna använde knäortos i fyra veckor.

I delstudie 1 undersöktes 14 patienter kliniskt efter tio år, samt radiologiskt med magnetkamera (MRT) två och tio år efter en främre korsbandsrevision med återskördad patellarsena. De kliniska långtidsresultaten var överlag dåliga och tagstället på knäskålsenan hade inte normaliserats radiologiskt efter tio år. Någon skillnad förelåg inte mellan två och tio års kontrollerna avseende tagställets utseende på MRT.

I delstudie 2, som var en prospektiv randomiserad studie med 7 års uppföljning, undersöktes 71 patienter med primär främre korsbandsskada som opererats med antingen BPTB eller HT autograft. De objektiva och subjektiva resultaten uppvisade ingen signifikant skillnad mellan de olika grafttyperna. Majoriteten av de postoperativa mätvärdena var dock i båda grupperna signifikant bättre än de preoperativa värdena. Någon skillnad i tagställesmorbiditet noterades ej heller mellan grupperna.

I delstudie 3 deltog 124 patienter. Förekomst av artros bedömdes och jämfördes retrospektivt 7 år efter rekonstruktion med antingen BPTB eller HT autograft. Dessutom bedömdes hur förekomst av eventuella meniskskador hos patienterna påverkade utvecklingen av artros. Med slätröntgen noterades ingen skillnad mellan grafttyperna i förekomst av artros, där artrosgraden bedömdes enligt både Ahlbäck's och Fairbank's klassificeringar. Ett tydligt samband noterades däremot mellan förekomst av meniskskador registrerade och behandlade antingen innan, under eller efter rekonstruktionen och utveckling av artros i det korsbandsopererade knäet.

I delstudie 4 togs biopsier med hjälp av ultraljud från den centrala och laterala delen av tagstället på knäskålsenan. Tolv patienter undersöktes tio år efter att de genomgått revisionskirurgi av främre korsbandet med hjälp av återskördad BPTB autograft. Histologin som bedömdes ljusmikroskopiskt visade en oordnad fiberstruktur med ökat antal celler och kärl både centralt och perifert i den knäskålsenan varifrån vävnad återskördats 10 år tidigare, jämfört med en frisk knäskålssena. Ultrastrukturen som bedömdes i elektronmikroskop var avvikande med patologisk cellstruktur och förändrad fördelning av fibrillstorleksklasser jämfört med normal knäskålsena.

Sammanfattningsvis kan p.g.a. både dåliga kliniska resultat och patologiska radiologiska, histologiska och ultrastrukturella fynd, återskördning av den centrala tredjedelen av knäskålsenan vid främre korsbandskirurgi inte rekommenderas. Dessutom förefaller både BPTB och HT autograft vara likvärdiga val på lång sikt både med avseende på kliniska resultat och artrosutveckling efter främre korsbandskirurgi.

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