Acute knee injury with focus on ligaments other than the anterior cruciate

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LUND
UNIVERSITY

DOCTORAL DISSERTATION

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Abstract:

Acute knee injury is a common reason for attendance to orthopaedic services. Clinical examination after such injures can be difficult. For this reason, the use of magnetic resonance imaging (MRI) has become more widespread. In the first half of this thesis I investigate the agreement between initial clinical examination and subacute MRI, and the equivalency of clinical and MRI based grading of medial collateral ligament (MCL) injury. In the second half I describe the long-term outcome after acute posterior cruciate ligament (PCL) injury and acute medial collateral ligament (MCL) injury managed non-operatively. The thesis is based on a consecutive cohort of 1145 acute knee injuries with subacute MRI prospectively registered in 2002-2008. Follow-up including clinical examination, radiography and patient-reported outcomes was conducted for patients 11 years after PCL and MCL injury. Knee subspecialists had the highest agreement in clinical examination compared to MRI with ACL injury while we found no significant differences for other ligament injuries or lateral patella dislocation (LPD). Kappa analysis of clinical versus MRI grading of the MCL showed moderate agreement. After PCL injury patients display a large variation in radiographic posterior tibial translation (RPTT). Patients with more severe RPTT (>3.7mm), had worse scores in the KOOS symptoms sport/recreation, quality of life and KOOS4. All follow-up MRIs displayed continuity of the PCL. Outcomes were similar in patients with MCL grade II compared to grade III injury. Results were also similar in all KOOS subscales after MCL grade II/ACL compared to MCL grade III/ACL injury, however the Tegner score was lower in the latter. In summary, our findings highlight the importance of MRI in the evaluation of patients after acute knee trauma. PCL injuries show continuity on MRI at high frequency at long-term follow up. MCL grade III injuries display largely similar outcome to MCL II injuries with and without ACL injury after non-operative management.

Key words: knee injury, medial collateral ligament, posterior cruciate ligament.

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Table of Contents

Abstract

Acute knee injury is a common reason for attendance to orthopaedic services. Clinical examination after such injures can be difficult. For this reason, the use of magnetic resonance imaging (MRI) has become more widespread. In the first half of this thesis I investigate the agreement between initial clinical examination and subacute MRI, and the equivalency of clinical and MRI based grading of medial collateral ligament (MCL) injury. In the second half I describe the long-term outcome after acute posterior cruciate ligament (PCL) injury and acute medial collateral ligament (MCL) injury managed non-operatively. The thesis is based on a consecutive cohort of 1145 acute knee injuries with subacute MRI prospectively registered in 2002-2008. Follow-up including clinical examination, radiography and patient-reported outcomes was conducted for patients 11 years after PCL and MCL injury. Knee subspecialists had the highest agreement in clinical examination compared to MRI with ACL injury while we found no significant differences for other ligament injuries or lateral patella dislocation (LPD). Kappa analysis of clinical versus MRI grading of the MCL showed moderate agreement. After PCL injury patients display a large variation in radiographic posterior tibial translation (RPTT). Patients with more severe RPTT (>3.7mm), had worse scores in the KOOS symptoms sport/recreation, quality of life and $KOOS_4$. All follow-up MRIs displayed continuity of the PCL. Outcomes were similar in patients with MCL grade II compared to grade III injury. Results were also similar in all KOOS subscales after MCL grade II/ACL compared to MCL grade III/ACL injury, however the Tegner score was lower in the latter. In summary, our findings highlight the importance of MRI in the evaluation of patients after acute knee trauma. PCL injuries show continuity on MRI at high frequency at long-term follow up. MCL grade III injuries display largely similar outcome to MCL II injuries with and without ACL injury after non-operative management.

Thesis at a glance

Paper	**I**	**II**	**III**	**IV**
Study type	Cohort	Cohort	Cohort	Cohort
Main aims	Define agreement between acute clinical examination and subacute MRI findings	Compare clinical with MRI based gradings of medial collateral ligament injury	Define the long-term outcome after PCL injury treated non-operatively	Define the long-term outcome after medial collateral ligament injury treated non-operatively
Data inclusion	All patients with acute knee injury	Patients from cohort I examined by a specialist	Acute PCL injury	Acute medial collateral ligament injury
Study population (n)	*1145*	*362*	*18*	*154*
Results	Knee subspecialists had the highest agreement with anterior cruciate ligament injury. We did not find statistically significant differences for other injuries.	Kappa analysis showed moderate agreement between clinical and MRI gradings.	All follow-up MRIs displayed continuity of the PCL. Patients with more severe radiographic posterior tibial translation (RPTT) [>3.7mm], had worse scores in the KOOS symptoms sport/recreation, quality of life and $KOOS_4$ than those with RPTT ≤3.7mm.	Outcomes were similar in patients with MCL grade II compared to MCL grade III injury. Results were also similar in all KOOS subscales after MCL grade II/ACL compared to MCL grade III/ACL injury, however the Tegner score was lower in the latter.
Conclusions	Clinical diagnosis after acute knee injury is relatively unreliable vs MRI findings.	Agreement between clinical and MRI grading of MCL injuries is at least moderate regardless of the presence of cruciate ligament injury.	Acute PCL injuries treated non-surgically display a high degree of PCL continuity on follow-up MRI. However, there is a large variation of posterior tibial translation with higher values being associated with poorer patient-reported outcomes.	Non-operatively managed grade III MCL injuries with and without concomitant ACL injury achieve largely similar patient-reported and radiographic outcomes to their grade II counterparts.

Plain English summary

Acute knee injury is a common reason for seeking medical care. Prior research has suggested that physical examination in the early stages after injury can be difficult and unreliable. This may be due to factors such as pain and muscle guarding but also the level of experience of doctors performing the initial examination. Common potential soft-tissue structures that can be injured include the ligaments inside the knee, the cruciate ligaments, and the ligaments on either side of the knee, the collateral ligaments.

While some knee injuries, such as anterior cruciate ligament (ACL) injuries are common, other ligament injuries are not and are thus more difficult to study. Posterior cruciate ligament (PCL) injury is rare and there is very limited data regarding long-term outcome. While some collateral ligament injuries are more common there is also a lack of high-quality long-term studies.

Paper I compares the physical examination findings after acute knee injury with the results of MRI in a group of 1145 patients over a 6-year period. I found that physical examination had, overall, moderate accuracy in diagnosing injuries as compared to MRI. Accuracy was best for ACL injuries examined by an experienced examiner. Had diagnosis been based solely on initial physical examination, then many serious injuries would have been missed, highlighting the importance of MRI in this group of patients.

Paper II compares two methods of grading of collateral injury (physical examination and MRI classification). I found there to be at least moderate agreement between these two methods indicating that the two gradings are not entirely equivalent.

Paper III studies patients who had sustained PCL injuries using physical and radiographic examination as well as patient reported outcome measures (a specific type of questionnaire) 11 years after injury. I found that patients with a higher grade of joint laxity tended to have worse outcome on their questionnaire. The injured ligament appeared to have healed in continuity in all patients who underwent repeat MRI at follow-up.

Paper IV studies patients after medial collateral ligament injury in broadly the same way as paper III. I found that outcome without surgical treatment was generally similar for high and moderate grades of injury even when that injury was combined with an ACL injury.

In summary, I found that MRI was a valuable diagnostic tool after acute knee injury, that PCL injuries heal at a high frequency and that high grade medial collateral ligament injuries treated without surgery achieve largely similar outcomes to moderate grade injures in the long-term.

Sammanfattning på Svenska

Mjuka knäledsskador, det vill säga skador mot mjukdelsstrukturer såsom ligament, brosk och menisker, utgör en betydande andel av de patienter som handläggs vid en ortopedisk akutmottagning. Under perioden 2002 till 2008 har subakut magnetkameratomografi (MRT) utförts vid Helsingborgs Lasarett som klinisk rutin vid knäledsdistorsion följt av knäledssvullnad inom 24 timmar. Samtliga patienter som omhändertagits enligt dessa rutiner har registrerats och en databas innehållande 1145 unika fall skapats.

Avhandlingen syftar till att utvärdera det akuta omhändertagandet av patienter med knäskador som sökt vård under den här perioden samt att beskriva utfallet efter kollateralligament- och bakre korsbandsskador som behandlats icke-operativt.

I delarbete I utvärderas överensstämmelse mellan kliniska undersökningsfynd i akutskedet jämfört med fynd på MR-bilder inom median 8 dagar från skadetillfället. Knäspecialister visade sig ha bäst överenstämmelse mellan klinisk undersökning och MR fynd med främre korsbandsskada. Dock såg man ingen skillnad för kollateralligamentskada, patellaluxation eller bakre korsbandsskada.

I delarbete II jämfördes klinisk undersökning-, och MR för gradering av mediala kollateralligamentskador. Kappa analys visade måttlig överensstämmelse mellan dessa två metoder.

I delarbete III undersöktes utfallet 11 år efter bakre korsbandsskada behandlad icke-operativt. Patienter genomgick en uppföljning med patientrelaterade utfallsmått samt klinisk- och radiologisk undersökning. Det finns en stor variation i graden av bakre tibiatranslation vid uppföljning. Patienter med högre grad av bakre tibiatranslation tenderade ha sämre patientrelaterat utfall.

I det sista delarbetet undersöktes utfallet 11 år efter medial kollateralligamentskada behandlad icke-operativt. Patientrelaterade utfallsmått var snarlika för grad II och III skador både med och utan främre korsbandsskador. Det fanns inga signifikanta skillnader i prevalensen av radiologisk artros.

Sammanfattningsvis; MR är ett värdefullt verktyg vid knäledsskada med hemartros. Klinisk- och MR graderingar av mediala kollateralligamentskador är inte jämlika. Högre grad av bakre tibiatranslation efter bakre korsbandsskada är associerad med sämre patientrelaterat utfall. Utfall är snarlikt efter grad II och III medial kollateralligamentskada vid långtidsuppföljning.

List of papers and conference abstracts

Brown JS, Frobell RB, Isacsson A, Englund M, Olsson O. Agreement Between Clinical Examination and Magnetic Resonance Imaging in Acute Knee Trauma with Hemarthrosis. Clin J Sport Med. 2022 Jul 1;32(4):401-406.

Brown JS, Olsson O, Isacsson A, and Englund M. Clinical versus MRI grading of the medial collateral ligament in acute knee injury. Res Sports Med. 2022 May 27:1-5.

Brown, J.S., Mogianos, K, Roemer, F.W, Isacsson,A, Kumm, J. Frobell, R. Olsson, O. Englund, M. Clinical, patient-reported, radiographic and magnetic resonance imaging findings 11 years after acute posterior cruciate ligament injury treated non-surgically. BMC Musculoskelet Disord 2023 24, 365.

Brown JS, Isacsson A, Frobell R, Olsson O, Englund M. Clinical, patient-reported and radiographic findings 11 years after acute collateral ligament injury. In manuscript.

Conference abstracts

Agreement Between Clinical Examination and Magnetic Resonance Imaging in Acute Knee Trauma with Hemarthrosis: A Prospective Cohort Study of 1145 Patients. European Federation of National Associations of Orthopaedics and Traumatology (EFORT) conference 2019.

Clinical, Patient-Related, Radiographic and Magnetic Resonance Imaging Findings 11 Years After Acute PCL Injury Treated Non-Surgically. European Federation of National Associations of Orthopaedics and Traumatology (EFORT) conference 2019. Poster presentation.

Abbreviations

ACL	anterior cruciate ligament
AKP	acute knee project
CI	confidence interval
EDD	emergency department doctor
ICC	intra class correlation coefficient
LCL	lateral collateral ligament
MCL	medial collateral ligament
MRI	magnetic resonance imaging
OSK	orthopaedic specialist knee
OSO	orthopaedic specialist other
OT	orthopaedic trainee
PCL	posterior cruciate ligament
PLC	posterolateral corner
ROA	radiographic osteoarthritis
RPTT	radiographic posterior tibial translation

Overall aims

Paper I:

To define the agreement between acute clinical examination findings and findings of subacute magnetic resonance imaging (MRI) in patients with acute knee injury.

Paper II:

To compare clinical with MRI based gradings of the medial collateral ligament after acute knee injury.

Paper III:

To define the long-term outcome after acute PCL injury treated non-operatively.

Paper IV:

To define the long-term outcome after acute collateral ligament injury treated non-operatively.

Conflicts of interest and funding

I have no conflicts of interest to declare.

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Background

Epidemiology

Acute knee injuries are common with an incidence of 151 per 100 000 inhabitants and as such make up a significant proportion of the injuries presenting to orthopaedic clinics and emergency departments [87]. The medial collateral ligament (MCL) is one of the most frequently injured knee ligaments with an incidence of 41 per 100 000 [87]. The lateral collateral ligament (LCL) and the posterior cruciate ligament (PCL) on the other hand are more rarely injured, particularly in isolation [12]. The annual incidence of LCL injury is 10 per 100 000 and PCL between 2 and 4 per 100 000 [87,100]. In comparison the annual incidence of ACL injury is 77 per 100 000 [87].

Presentation and evaluation

A rapid joint swelling suggestive of a hemarthrosis often indicates serious joint injury even in the absence of obvious laxity at the initial clinical examination [22,102]. Clinical examination after acute injury has previously been shown to be difficult and potentially unreliable [31,102] and before the evolution of MRI, many patients required a diagnostic arthroscopy to ascertain what injury had been sustained [31,33,84]. This is obviously an invasive procedure requiring in most cases a general anaesthetic. Associated with this are challenges such as operating theatre time, which in an already stretched public healthcare system is at a premium, cost of operating theatre equipment and staff as well as morbidity associated with an operation, albeit a minor one. During the previous two decades the use of MRI in the evaluation of acute knee injuries has become more commonplace. While arthroscopy is still considered the gold standard of knee joint evaluation, MRI allows accurate evaluation in a non-invasive and cost-effective fashion and has the advantage of visualising the periarticular structures which are not seen during arthroscopy [60,61,74,76,80,91]. For these reasons MRI has, in practical purposes, largely superseded arthroscopy as the investigation of choice after acute knee injury. Few studies have been conducted however, regarding the agreement between clinical examination in everyday practice and MRI findings of acute knee injuries [31,85]. In

an effort to improve the identification of serious knee injuries after acute knee trauma a new follow-up pathway was introduced in the early 2000´s at Helsingborg Hospital, Sweden. The Acute Knee Project (AKP) ensured that patients deemed to be at high risk of serious knee injury were offered specialist clinical follow-up and modern imaging in a timely fashion.

Knee ligament anatomy and function

There are four major ligaments in and around the knee. The anterior and posterior cruciate ligaments (ACL and PCL) are intraarticular while the medial and lateral collateral ligaments (MCL and LCL) are extraarticular (Figures 1 and 2). In addition to the MCL and LCL there are other stabilising structures on the medial and lateral sides which make up complexes called the posterolateral and posteromedial complexes. The posteromedial complex consists of the MCL (which can be divided into superficial and deep portions) and the posterior oblique ligament (POL) (Figure 2). The superficial MCL has a single, oval femoral attachment slightly proximal and posterior to the medial epicondyle and two distal attachments, one to the semimembranosus tendon and the other, a broad bony attachment just anterior to the posteromedial crest of the tibia [65]. The deep MCL is a thickening of the medial joint capsule which blends posteriorly with the POL [65]. The MCL is the primary restraint to valgus motion but is also important for rotational stability [64]. The POL is a primary restraint to internal rotation and a secondary constraint to valgus motion [19]. The posterolateral complex (PLC) consists primarily of the LCL, popliteus tendon and the popliteofibular ligament (Figure 1) [48]. The LCL has a femoral attachment just proximal and posterior to the lateral epicondyle and attaches to the lateral aspect of the fibula head approximately 8mm from the anterior aspect [48]. The LCL is the primary restraint to varus motion [35] and together with the other components of the PLC prevents posterior tibial motion, varus motion and external tibial rotation [16]. The PCL is both larger and considerably stronger than the ACL [41]. It consists of two bundles (anterolateral and posteromedial) (Figure 1) which work in a codominant fashion to resist posterior tibial translation throughout knee range of motion and at higher flexion angles also internal rotation [57,120]. The femoral attachment of the PCL is semicircular or oval and lies on the medial intercondylar wall [71]. Distally it attaches along the posterior aspect of the tibial plateau, extending approximately 1 cm distal to the joint line [70]. The ACL is also made up of two bundles, the anteromedial and posterolateral which, similar to the PCL work in a codominant fashion. The anteromedial bundle is the primary restraint to anterior tibial translation while the posterolateral bundle tends to restrain the knee near full extension, in particular against internal rotation [92,123]. The femoral attachment of the ACL is a semicircular area on the lateral intercondylar wall [92]. The tibial attachment is to a fossa anterior and lateral to the anterior tibial spine [7]. In contrast to the ACL,

the PCL is also covered by synovial membrane intraarticularly which is believed to aid in healing of the injured ligament. The ACL, on the other hand has generally been considered not to have significant healing capacity although this has been questioned in recent years [28].

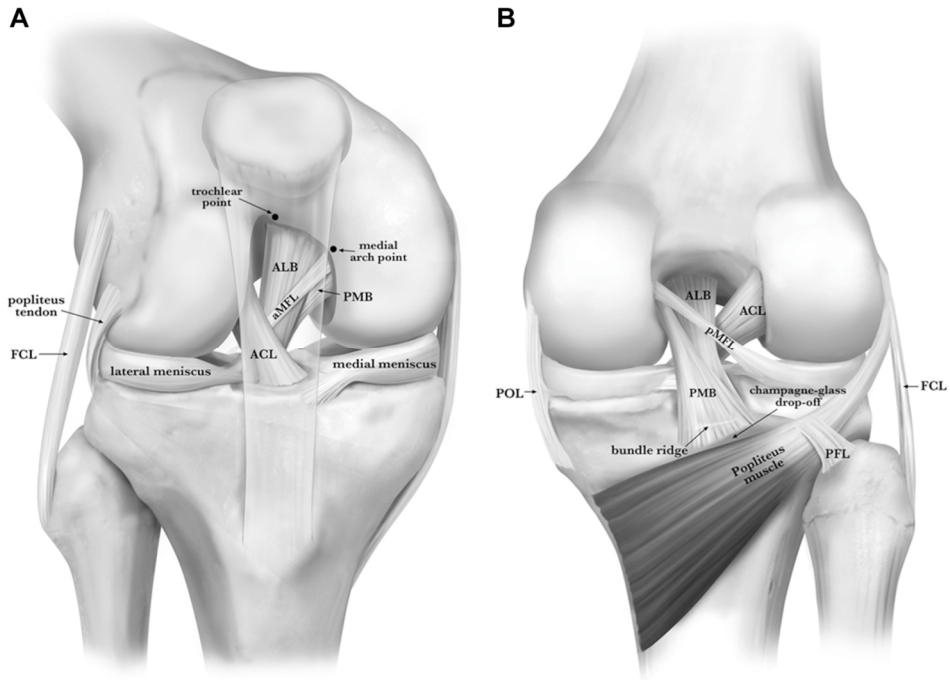

Figure 1: The Intra- and extraarticular ligaments of the knee from anterior (A) and posterior (B). FCL (fibular collateral ligament or lateral collateral ligament), PFL (popliteofibular ligament), POL (posterior oblique ligament), ALB (anterolateral bundle of the posterior cruciate ligament), PMB (posteromedial bundle of the posterior cruciate ligament), a/pMFL (anterior/posterior meniscofemoral ligament). Reproduced with permission from Kennedy, Wijdicks and LaPrade (2013) [57].

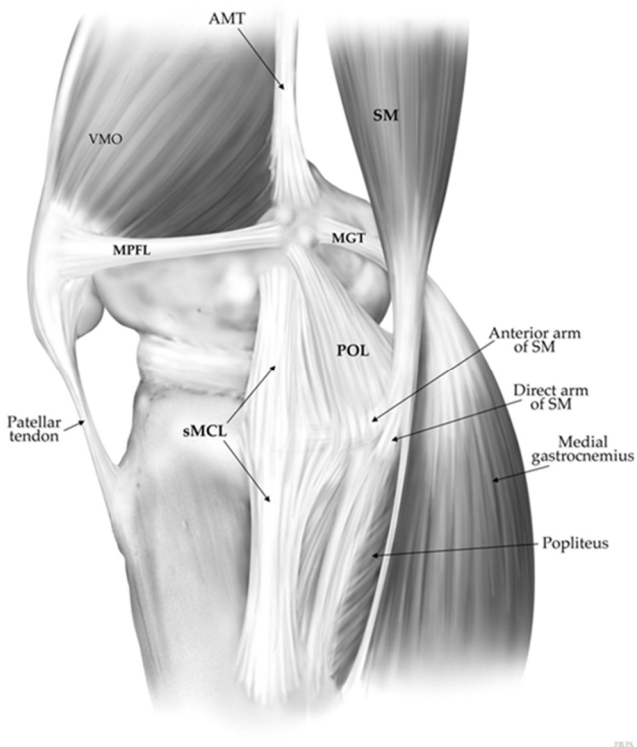

Figure 2: The medial structures of the knee. sMCL (superficial medial collateral ligament), POL (posterior oblique ligament), AMT (adductor magnus tendon), VMO (vastus medialis oblique), MPFL (medial patellofemoral ligament), MGT (medial gastrocnemius tendon). Reproduced with permission from LaPrade et al 2007 [65].

Normal ligament appearance on MRI

On sagittal images the PCL is seen as a thick band of uniformly low signal intensity from the femur to the tibia in contrast to the ACL which is usually less well defined and has a higher signal intensity. On coronal images the MCL is seen as a uniformly low intensity band [58]. The LCL is also a low intensity structure though usually has an oblique course and must be viewed on sequential coronal images [18,36].

Posterior cruciate ligament injury

PCL injury occurs rarely in comparison to other knee ligament injuries and is therefore challenging to study. PCL injuries are commonly graded clinically as

grade I, II or III based on the degree of posterior translation on the posterior drawer test. Grade I injuries are defined by increased posterior tibial translation but with the tibia not being flush with the anterior surface of the femoral condyles. With grade II injuries the tibia is flush with the femoral condyles and with grade II injury the tibia translates posterior to the femoral condyles [98]. A more objective method of measuring posterior tibial translation is radiographically which is considered a part of the evaluation by some clinicians, although this is not universally accepted [23,106]. Non-operative treatment of isolated PCL injuries has been an accepted alternative for many years and there are several studies documenting good outcome and high levels of return to sport even for high grade injuries [2,89,99,107]. There are however proponents of surgical treatment, generally for higher grade injuries and those associated with other ligament injuries although evidence for this standpoint is not strong [4,116,120]. Surgery is normally performed arthroscopically although an open, posterior technique is preferred when repairing tibial avulsion injuries [55]. In comparison to non-operative treatment, surgical treatment is associated with a higher risk of complications such as thromboembolic events, infection, compartment syndrome, arthrofibrosis and vascular injury [4,17,51]. In addition, almost 9% of patients treated with PCL reconstruction in a recent study attended unscheduled acute healthcare visits in the first 90 days after surgery [51]. The potential burden of complications after surgical treatment clearly not only impacts orthopaedic services but the healthcare system as a whole. PCL injury can lead to chronic posterior tibial translation and it is commonly believed that this is associated with poorer outcome both in terms of function, and development of osteoarthritis. Whether the degree of posterior laxity is associated with worse outcome is still controversial and several studies have not been able to demonstrate this [94,105,112]. In recent years PCL specific braces have become a common part of the non-operative treatment of PCL injuries. These provide support behind the leg to reduce the degree of posterior sag and hold the knee in a more anatomic position with the hope that when the PCL heals it does so without excessive elongation which may otherwise predispose to long-term posterior laxity [47,50]. As the treatment routine in the AKP study predates the widespread use of these braces there were no patients treated in this way in the thesis cohort. This is however now standard practice at Helsingborg hospital.

Collateral ligament injury

In routine practice an assessment of the grade of injury is usually made at the initial clinical examination. The following classification system was used in the acute knee project as it is well known to clinicians and in common use both at the hospital's emergency and orthopaedic departments: Grade I is characterised by mild to

moderate pain limited to the ligament, full stability to stress at both 0 and 30° of flexion with a firm end point. Grade II is characterised by moderate to severe pain localised to the region of the ligament, full stability at 0° flexion but unstable to stress at 30° of flexion with a soft endpoint. Grade III injuries are characterised by less severe pain than grade I and II (due to complete diastasis of the ligament) and are unstable to stress at 0 and 30° of flexion with an indefinite or absent end-point [27]. Other methods of grading exist and there is unfortunately no clearly accepted standard classification system [45,115]. The presence of a concomitant ACL rupture will generally result in a greater degree of coronal laxity [81]. Although grading by an experienced clinician has traditionally been the accepted gold-standard, MRI can potentially give important information regarding injury characteristics such as Stener-like lesions where the MCLs distal attachment is displaced superficial to the pes anserinus which becomes interposed between the ligament and its previous attachment.

The optimal treatment strategy for grade II and III collateral ligament injury remains controversial. While there seems to be reasonable agreement that Stener-like lesions of the MCL should be treated surgically [20,111,114], evidence exists for both operative and non-operative management of MCL injuries both with, and without ACL injury [38,42,46,72,73,101,110,118,124]. Traditionally the vast majority of MCL injuries have been treated non-operatively even in elite level athletes with high levels of return to sport documented [46,67]. Surgery is generally performed with an open or percutaneous surgical technique. Both repair and reconstruction are described with repair being reserved for acute and sub-acute injuries [34]. There are various described methods of reconstruction though none has been shown to be clearly superior [69]. Potential surgical complications are infection, arthrofibrosis and reduced range of motion, and persistent laxity [111,118]. It is thought that the rate of certain complications such as arthrofibrosis are lower with modern surgical and rehabilitation techniques although there is still no high-quality evidence that the results are superior to non-operative management. Operative treatment of grade III lateral collateral ligament (LCL) injury has traditionally been recommended especially when combined with ACL injury [54,62] although more recent research has demonstrated faster return to sport with non-operative treatment of isolated LCL injuries [15]. Surgery for LCL injuries is commonly performed using an open surgical technique. Both repair and reconstruction are described with the optimal method being controversial. Numerous surgical techniques for reconstruction have been described [66,68,79,103]. Potential complications include infection, arthrofibrosis and loss of range of movement, peroneal nerve injury and persistent laxity [35]. Like PCL injury, the relatively low incidence and potential for concomitant knee injuries makes LCL injury a challenge to study.

Methodology

Patient population and initial management

Helsingborg hospital is a district general hospital in southwest Sweden and serves a catchment area of predominantly urban mixed with rural populations. At the time of study inception, the catchment area population was 155 870, rising by 81 549 in 2004 when services from nearby Ängelholm hospital were incorporated. In 2007 the total population was 246 999 [87]. Patient recruitment was conducted between January 2002 and February 2008. All patients with acute knee trauma and hemarthrosis were referred for subacute MRI after an initial clinical examination. Hemarthrosis was considered present if there was a bloody aspirate from the knee joint or a clear history of rapid joint effusion within 24 hours after knee trauma. Patients either sought care in the emergency department or were referred to an acute knee clinic by community physicians. Emergency department doctors and referring community physicians were provided with written information regarding the study and how referrals should be made. Due to staffing patterns at the hospital patients referred to the acute knee clinic were assessed by an orthopaedic specialist whilst patients presenting to the emergency department were most commonly assessed by emergency department doctors or orthopaedic trainees. If there was clinical suspicion of a fracture, the patient was referred for conventional radiography. Knees with fractures seen on conventional radiographs, apart from osteochondral and ligament avulsion fractures, were not eligible for the study. Patients with cortical depression fractures on MRI were, however, eligible for inclusion (Figure 3). All MRI´s were evaluated at specific radiology rounds held twice weekly with knee specialists, physiotherapist, nurse co-ordinator and musculoskeletal radiologist present. Patient details and MRI findings were recorded in a prospective manner. The dissertation is based on the final cohort of 1145 knees.

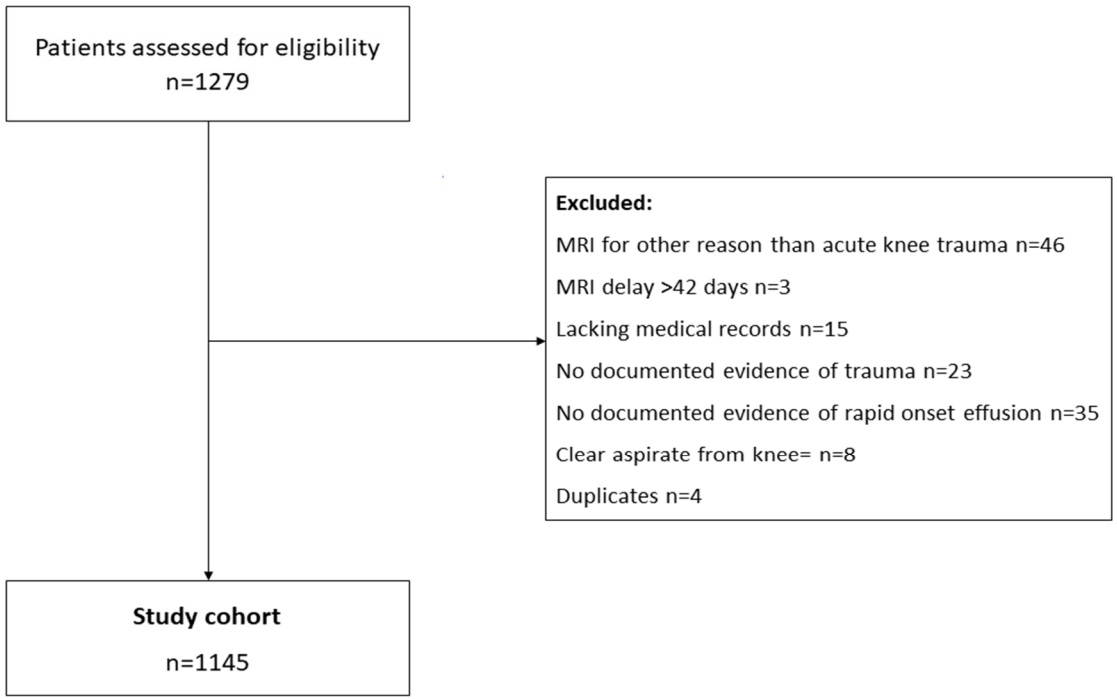

Figure 3. Reasons for exclusion.

Findings of initial clinical examination were retrieved from patient records. Examiners were classified as either emergency department doctor (EDD), orthopaedic trainee (OT), orthopaedic subspecialist other (OSO), or orthopaedic specialist knee (OSK).

Hemarthrosis was defined as documentation of either bloody aspirate from the knee at initial examination or as a history of rapid onset effusion over <24 hours following trauma.

Antero-posterior (A-P) laxity was determined by documentation of results from either the anterior drawer or Lachman test and was recorded as normal or increased.

Medial and lateral collateral ligament injuries were recorded according to documentation of the graded varus/valgus stress test as grade I, II or III [27].

A diagnosis of LPD was suspected based on a history consistent with LPD and/or clinical signs compatible with LPD such as tenderness over the medial patella retinaculum.

Where no specific injury was suspected a diagnosis of knee distortion/sprain was assigned.

Knee magnetic resonance imaging

Two different MRI scanners were used: a 1.5 T imager (Gyro-scan, Intera, Philips, Eindhoven, the Netherlands) and a 1.0 T imager (Impact, Siemens, Erlangen, Germany), both using a circular polarized surface coil. Patients were examined with a T2-weighted turbo spin-echo sequence (tSEPdT2) and a T2-weighted turbo short tau inversion recovery sequence (tSTIRT2) in the coronal and in the sagittal views [31]. In keeping with routine clinical practice MRI´s were assessed by several experienced musculoskeletal radiologists who were not blinded to the potential findings of clinical examination. MRI findings were classified and collected according to Khanna et al [59] with the modifications as outlined below.

ACL and PCL ruptures were recorded as present/absent. Where present, injuries were categorized into total or partial ruptures, or graft rupture in those with a previously reconstructed ligament. MCL and LCL ruptures were graded as I (oedema without signs of discontinuity), II (discontinuity visualized but without displacement) and III (discontinuity with displacement). Post-traumatic signs of lateral patella dislocation (LPD) were considered present when isolated fresh post-traumatic bone marrow lesions (BMLs) were present in the medial part of the patella and/or in the anterior part of the lateral femoral condyle [25]. In the absence of

ligament, meniscal or cartilage injury or BMLs the MRI was reported as non-specific soft tissue knee injury.

For the purposes of paper I, a major ligament injury was defined as grade II or III collateral ligament injury, ACL rupture or PCL rupture as visualised on MRI. In the case of multiple structural injuries, the primary injury was defined as ACL rupture, PCL rupture, or LPD and concomitant injuries regarded as accessory injuries. In the absence of cruciate ligament injury or LPD the primary diagnosis was regarded as the collateral ligament injury. As such the primary clinical diagnosis was defined as a diagnosis identifying the primary injury with or without identification of accessory injuries.

Routine management of ligament injuries during the study period

Anterior and posterior cruciate ligament injuries were treated initially non-operatively. Acute collateral ligament injuries (with and without concomitant cruciate ligament injury) were generally treated non-operatively with a hinged knee brace with range of movement limited to 0-90 degrees and weight-bearing as tolerated for a period of 6 weeks. If a collateral ligament injury was suspected on initial clinical examination brace treatment was initiated the same day. In other cases, brace treatment was initiated within days of the MRI. All patients were instructed to follow a physiotherapist guided rehabilitation program and were scheduled for follow-up and brace removal at 6 weeks in the case of collateral ligament injury. Continued rehabilitation was advised at this time. With the exception of cases where acute surgery was deemed necessary, decisions to reconstruct ligaments were deferred until a routine follow-up appointment at around 3 months.

Long-term follow-up of PCL and MCL injuries

Long-term follow-up was conducted between 2017 and 2019. Patients were identified from the AKP cohort and contacted by telephone on at least three occasions. If they were not contactable by telephone a letter of invitation with information about the study was posted to their registered address. Patients who were not contactable or did not attend for 2 scheduled appointments were considered lost-to-follow-up. Plain radiographs were performed at the same visit as the clinical follow-up. MRI´s were scheduled as close to clinical follow-up as possible.

Clinical follow-up

Height and weight were recorded, and range of motion and ligamentous laxity were assessed. Valgus/varus laxity was graded according to Fetto & Marshall [27]. The Lachman test was graded as per Hefti *et al* [44]. In the cases post PCL injury the posterior drawer test was graded according to Rubenstein *et al* [98].

Radiographic follow-up

The anteroposterior projections were obtained in a weight-bearing position with the knee flexed 30° – 50° [9]. The Merchant view projection was obtained in standing with the knee flexed 40° – 60° [10]. For patients post PCL injury radiographic posterior tibial translation (RPTT) was assessed using the Puddu axial radiograph. This is a bilateral view and allows the posterior tibial translation under the effect of gravity to be calculated using the contralateral knee as the reference [94]. The Puddu axial radiograph is performed in the supine position with the knees flexed to 70° with the patient holding the cassette as shown in figure 4. RPTT was measured by drawing a line tangential to the femoral condyles (A-A_1). The length of the perpendicular line (B) between the anterior tibial profile (C) and the centre of the femoral groove was then measured (Figure 5). The difference in the length of line B between the injured and uninjured knee is the RPTT. The method relies on the contralateral knee not being translated posteriorly in order to give an accurate measurement of the degree of posterior translation of the affected knee. It is therefore important that the contralateral PCL has not been injured.

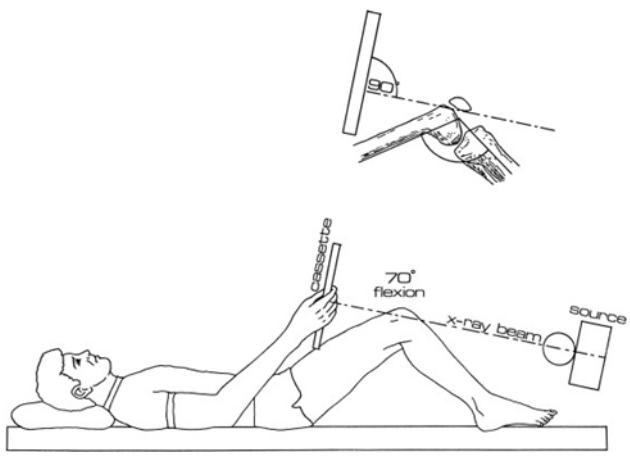

Figure 4. Patient positioning for the Puddu axial radiograph. Reproduced with permission from Puddu et al (2000)[94].

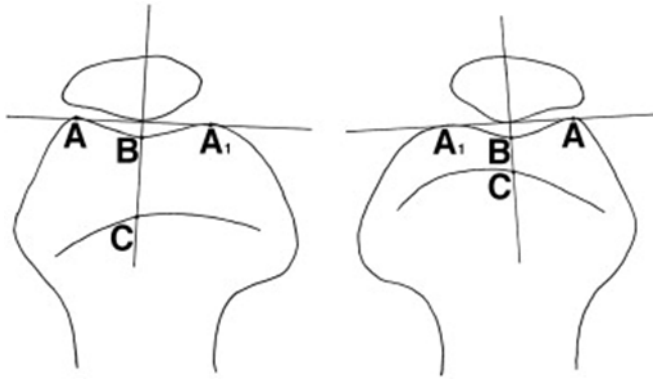

Figure 5. Measurement of RPTT using the Puddu axial radiograph. Reproduced with permission from Puddu et al (2000)[94].

Anterosuperior and Merchant view radiographs were evaluated and classified for radiographic osteoarthritis by one experienced musculoskeletal radiologist according to the OARSI atlas [6].

Radiographic osteoarthritis was defined according to Englund at al 2003 [26]: OARSI osteophytes grade 2 or more, OARSI joint space narrowing (JSN) grade 2 or more, or sum of JSN and osteophyte grades of ≥2 within one compartment (medial tibiofemoral, lateral tibiofemoral or patellofemoral). This definition approximates Kellgren Lawrence grade 2 or higher.

Puddu radiographs were assessed by a medical student trained in the evaluation of these views on two separate occasions. Radiographs were reevaluated by a senior orthopaedic trainee. Intra- and inter-rater reliability were calculated.

Follow-up MRI's after PCL injury were assessed by a fellowship trained sports knee and shoulder surgeon. The ligament was defined as having continuity when low-intensity signals representing the ligament were continuous from the femur to the tibia regardless of the shape and configuration [5,93].

Patient-reported outcome

Knee injury and osteoarthritis outcome score (KOOS) and the Tegner activity scale were completed by participants. In addition, EQ5D-EQ-VAS and the Activity Rating Scale were used in the PCL cohort.

The KOOS score has been a widely accepted outcome measure for several decades. It is used commonly when reporting outcomes after knee ligament injury and is utilised by large registries such as the Swedish Knee Ligament registry. It consists of five subscales: pain, symptoms, activities of daily living, sport/recreation and quality of life. In addition, an aggregate score can be calculated called the $KOOS_4$,

based on the average score of four of the five KOOS subscales (pain, symptoms, sports/recreational, and quality of life) avoiding the potential ceiling effect in the subscale activities of daily living, which relatively young and active patients rarely have issues with [32,39]. Although not validated as an outcome measure in its own right it is recognised as a supplementary measure to the other five subscales by the team responsible for developing the KOOS and has been used in a number of large research studies [32,39,97,113].

The Tegner scale is a numerical scale from 0-10. Each value represents specific physical activities with higher values representing greater physical performance. It is commonly used in knee injury research [14]. The Activity Rating Scale, also common in knee injury research, is an alternative activity rating tool that focuses on specific activities such as pivoting during sport rather than on participation in specific types of sports [52]. It consists of four items with higher scores representing a higher frequency of participation in activities that are demanding for the knee.

EQ5D-EQ-VAS is an item included in the EQ5-D questionnaire and allows patients to estimate their overall state of health on a scale from 0-100 with zero representing the worst health imaginable and 100 the best [95].

Statistical methods

Paper I:

Sensitivity and specificity were calculated for major ligament injury and LPD combined as well as for each diagnosis separately. Logistic regression models were used to evaluate: a) the association between speciality of the examiner and agreement adjusted for time from injury to examination (considered a confounder) b) the association between time from injury to examination and agreement adjusted for speciality of examiner (considered a causal intermediate).

Paper II:

Sensitivity, specificity, and positive and negative predictive values were calculated for MRI as a test for grade II or III MCL injury. As there is little difference in the management of the MCL without injury and with grade I injury these grades were combined for a separate analysis resulting in 3 categories for both clinical and MRI gradings and agreement calculated using a Kappa with linear weighting. We chose a linear weighting as we deemed the difference between the three categories to be of equal importance, in contrast to quadratic weighting which would penalise lack of agreement in higher grades of category to a greater degree than lack of agreement in lower grades.

Paper III:

Analysis of normality was carried out using graphical analysis and Shapiro-Wilk tests. Comparisons of patient reported outcome were evaluated using analysis of variance to produce means with 95% confidence intervals (CI's). Differences between groups were evaluated using independent samples T-tests and the Mann-Whitney U-tests and presented as the differences between means or medians (Lehmann-Hodges estimates) respectively with 95% confidence intervals (CI). As the final cohort was small, we chose to present comparisons between groups in this way, rather than expressing p-values, in order to demonstrate the degree of uncertainty associated with the findings. Intra- and inter-rater reliability for tibial translation were assessed using intra class correlation coefficient (ICC).

Paper IV

Analysis of normality was carried out using graphical analysis and Shapiro-Wilk tests. Differences in patient reported outcomes between subgroups were analysed using Mann-Whitney U tests. Differences in the prevalence of radiographic osteoarthritis between subgroups were analysed with Fishers exact tests.

A p- value of 0.05 or less was considered significant in all papers.

Stata version 15 and SPSS version 25 were used for paper I. SPSS version 25 was used for paper II. SPSS version 27 was used for papers III and IV.

Ethical considerations

Patient's medical records were reviewed as part of the evaluation. Although all medical records were available, only those pertaining to the treatment of their knee injury were reviewed and as such it is unlikely that any particularly sensitive information would be revealed.

Patients were required to attend for follow-up at the hospital, undergo an examination and fill in questionnaires about their health status. Patients were invited to attend by a research nurse and were fully informed of the purpose of the study, which investigations were to be performed and that participation was entirely voluntary. At the follow-up visit they were again informed about the study and what their participation entailed. Written consent was obtained at this time.

Attending a follow-up visit entailed an investment in time for the patient which was not reimbursed. Follow-up was however, conducted during evenings and weekends to minimise impact on patients working lives. Patients were also allowed to choose between a wide variety of times to attend. Travel costs to and from the hospital were eligible for reimbursement. Although there was no direct benefit to the patient from

attending, they were offered the possibility of a follow-up and consideration of treatment of their knee problem at a later date if they, for example were not happy with the result of earlier treatment. There was a possibility that certain parts of the examination might be painful but if this was the case that part of the examination was discontinued.

During the radiographic examination patients were exposed to ionising radiation. Patients were informed about the nature of the radiographic examination and the relatively small radiation dose. In addition, the patient's recent history of other radiographic examinations was ascertained to ensure they were not exposed to unreasonably high levels of radiation. Lastly, patients were able to opt out of the radiographic analysis and maintain participation in the study.

Patient's personal details were used up until the point of inclusion whereupon they were assigned a study number which was used from this point on. Personal details were separately stored, securely, and managed by a research nurse.

Details of examiners, the results of their examination and if it was in agreement with MRI findings was included in the database. Theoretically this could be used to judge the competence of certain colleagues. As such as long time has passed since these examinations were performed essentially none of the examiners are in a position where this information would affect their career prospects. In addition, examiners were categorised depending on their speciality and no individuals were analysed as part of the study.

Ethical approval was obtained from the Lund regional ethics committee (2009/237, 2015/5, 2015/250).

Data inclusion

The total AKP cohort consisted of 1145 cases and was utilised for paper I. As examination by an experienced clinician has traditionally been the accepted standard for grading of MCL injuries only patients examined by a specialist were eligible for inclusion in paper II. Patients with PCL and medial collateral ligament injury were selected from the AKP cohort for papers III and IV (Figure 6). As only 14 of the 18 patients with LCL injury were followed-up I felt it would be appropriate to focus on MCL injury. LCL injuries were therefore not further studied in this thesis.

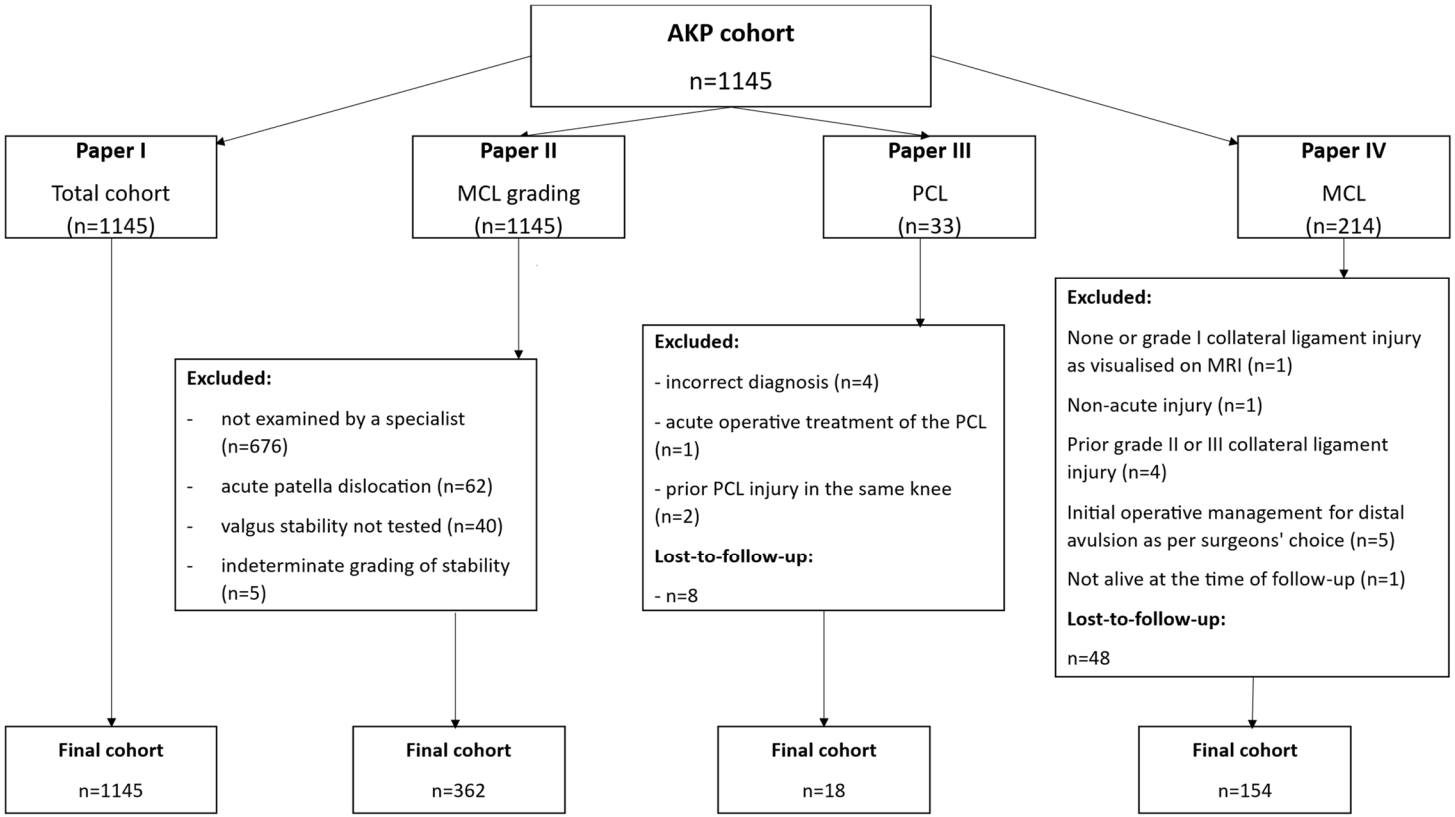

Figure 6. Inclusion flowchart for papers in the thesis.

Main results

Paper I

In paper I I investigated the agreement between initial clinical examination findings and sub-acute MRI identified injuries after acute knee injury. For this the AKP cohort of 1145 knees was used. Median time (25th and 75th percentile) from injury to clinical assessment for the cohort was 2 (1 and 7) days and from injury to MRI 8 (5 and 15) days.

The overall sensitivity and specificity of clinical examination for major ligament injury or lateral patella dislocation (LPD) vs MRI was 70 (95% CI 67-73) and 66 (95% CI 61-72) respectively. Specificity was generally high for all subspecialties. Sensitivity however, varied considerably with the highest values being for orthopaedic specialists.

Using emergency department doctors (EDD) as the reference category, the odds ratios (adjusted for time from injury to examination) for agreement between clinical diagnosis of ACL rupture and a ruptured ACL as visualized on MRI were 1.7 (95% CI 1.2-2.3), 1.9 (1.2-3.0) and 5.9 (3.7-9.5) for OT, OSO and OSK, respectively (Figure 7). For PCL, MCL and LCL grade II-III, and LPD I did not find such statistically significant differences though there was a trend toward better agreement with knee subspecialists and LPD (Figure 7). The odds ratios for a difference in time from injury to examination (adjusted for experience of examiner) were not statistically significantly different.

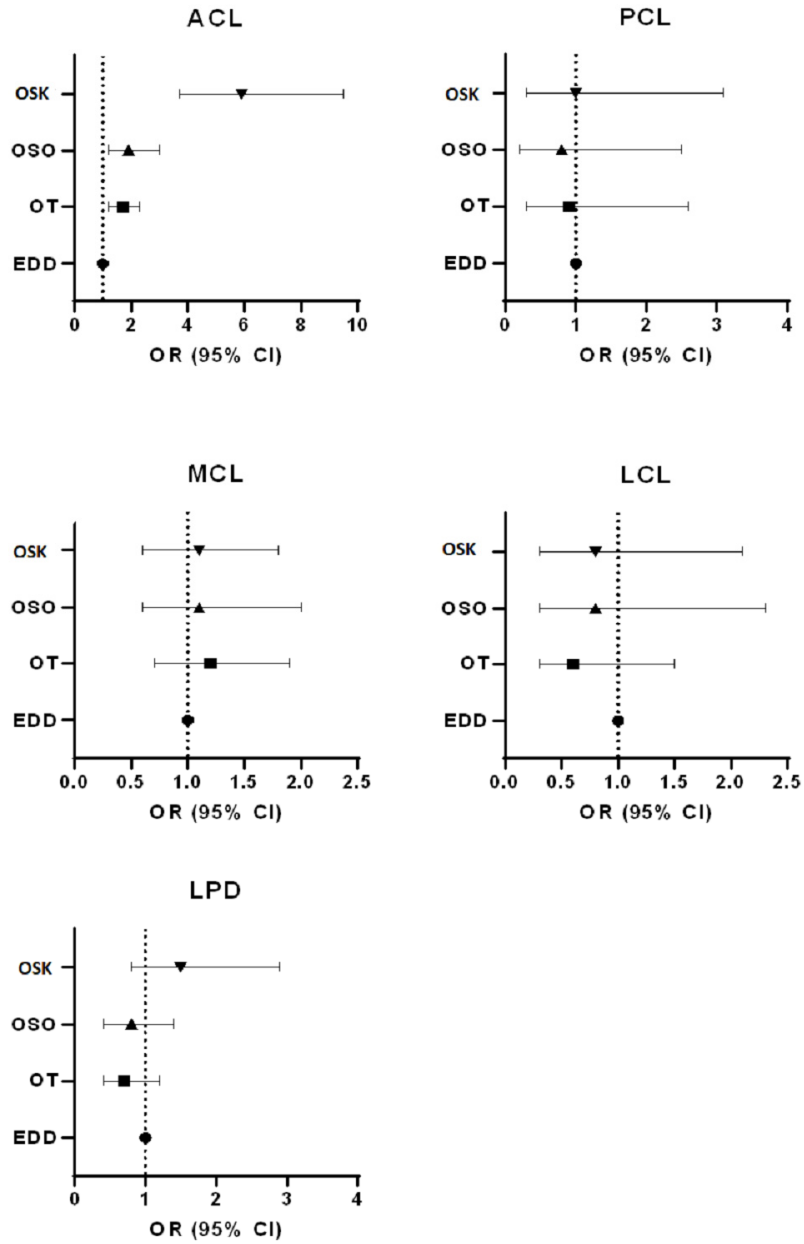

Figure 7. Logistic regression results for individual MRI identified diagnoses in relation to subspecialty of examiner adjusted for time from injury to examination (odds ratios with 95% confidence interval). ACL (anterior cruciate ligament), PCL (posterior cruciate ligament), MCL* (medial collateral ligament grade II-III), LCL* (lateral collateral ligament grade II-III), LPD (lateral patella dislocation). EDD (emergency department doctor [reference group]), OT (orthopaedic trainee), OSO (orthopaedic specialist other), OSK (orthopaedic subspecialist knee).

Paper II

In paper II I investigated the agreement between clinical and MRI based gradings of the MCL after acute knee injury. I identified MCL´s from the AKP cohort that were examined by a specialist or subspecialist (n=362). The sensitivity and specificity of MRI as a test for grade II or III MCL injury compared to clinical examination was 68% (95% CI 58 - 77%) and 90% (95% CI 86 - 93%), respectively. Kappa analysis yielded an agreement of 0.56 (95% CI 0.48 to 0.65) corresponding to moderate agreement [63]. Agreement was similar in patients with and without concomitant cruciate ligament injury. The prevalence of clinical grade II or III MCL injury was however low (26%) [Table 1].

Table 1. Distribution of clinical and MRI grade of MCL injury.

		MRI grade (n)			Total
		0 or I	II	III	
Clinical grade (n)	0 or I	241	19	8	268
	II	30	23	14	67
	III	0	8	19	27
Total		271	50	41	362

Paper III

In paper III I identified patients from the AKP cohort who had sustained an acute PCL injury and evaluated them at a mean of 11 years after injury. Eighteen patients (15 men), with a mean age of 33 (SD 14.2) years at injury were studied. The majority were injured during sporting activities (n=13). Seven patients sustained partial and 11 total PCL ruptures and half of the final cohort had also suffered injury to other ligaments at the time of PCL injury (Table 2).

Table 2. Injury patterns for patients with PCL injury

Cohort followed-up, n	18
Concomitant ligament injury, n	9
ACL (total)	4
ACL+MCL	*2*
ACL+MCL+LCL	*1*
MCL	4
LCL	1

ACL (anterior cruciate ligament). PCL (posterior cruciate ligament). MCL (medial collateral ligament). LCL (lateral collateral ligament).

Intra class correlation coefficients (ICC) were calculated for RPTT measurements and were excellent for both inter- and intra-rater reliability.

Median RPTT was 3.7 (25th-75th percentile 1.5-6.3) mm for the cohort. KOOS scores were generally poorer as the RPTT increased (Figure 8). Those with RPTT above the median had statistically significantly poorer outcome for symptoms (mean difference 14.5, 95% CI 7-22), sport/recreation (median difference 30, 95% CI 0 – 65), knee related quality of life (median difference 25, 95% CI 13-57) and $KOOS_4$ (median difference 22, 95% CI 9-34) than those with RPTT at or below median. There were however, no statistically significant differences in KOOS pain or ADL, EQ5D-EQ-VAS, or the Tegner or the Activity Rating Scales.

Fourteen patients underwent an MRI of the index knee at follow-up. All 14 showed continuity of the PCL.

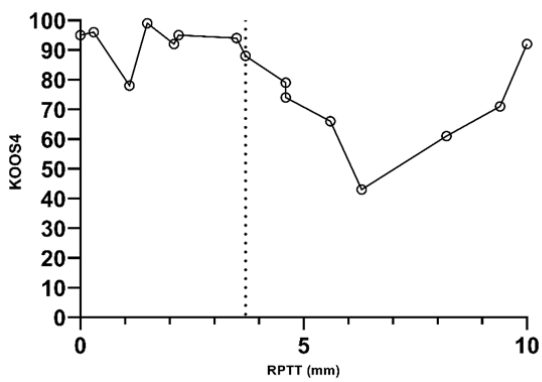

Figure 8. $KOOS_4$ score vs radiographic tibial translation (RPTT). Dotted vertical line represents median RPTT.

Paper IV

In the final paper I identified patients from the AKP cohort who had sustained medial collateral ligament injuries of MRI grade II and III and which had been treated non-operatively. Five patients treated with primary surgery for distal MCL avulsion at the discretion of the treating surgeon were excluded. One hundred and fifty-four patients participated in the follow-up at a mean of 11.5 years after injury (Table 3). The most common activities at injury were football and skiing.

Non-operatively managed MCL injuries showed similar outcomes in patients after MCL grade II compared to MCL grade III injury and MCL grade II compared to MCL grade II/ACL injury. Results were also similar in all KOOS subscales after MCL grade II/ACL injury compared to MCL grade III/ACL injury, however the Tegner score was lower in the latter (median 4 versus 2, p=0.038, 95% CI 0-2). Results in the KOOS subscales Sport/recreation, QOL, KOOS4 as well as the Tegner scale were worse with MCL grade III/ACL injury compared to MCL grade III injury alone (median 75 versus 90 [p = 0.015, 95% CI 0-30], 75 versus 88 [p=0.022, 95% CI 0-25], 81 versus 88 [p=0.052, 95% CI 0-17] and 2 versus 4 [p=0.014, 95% CI 0-2] respectively, [Figure 9]).

ACL reconstruction was more often performed in patients with MCL II/ACL injury than MCL III/ACL injury (42% versus 20%). The prevalence of ACL graft failure was higher in the MCL II/ACL subgroup than the MCLIII/ACL subgroup (18% vs 0%).

Table 3. Patient characteristics.

Cohort followed-up, n	154
Age at injury, mean (SD)	34.2 (12.8)
Age at follow-up, mean (SD)	46.2 (13.0)
Males, n (%)	89 (58)
Injured during sporting/recreational activity, n (%)	145 (94)
Ligament injuries, n (%)	
MCL II	18
MCL III	21
MCL II+ACL	66
MCL III+ACL	49

SD (standard deviation). ACL (anterior cruciate ligament). MCL (medial collateral ligament).

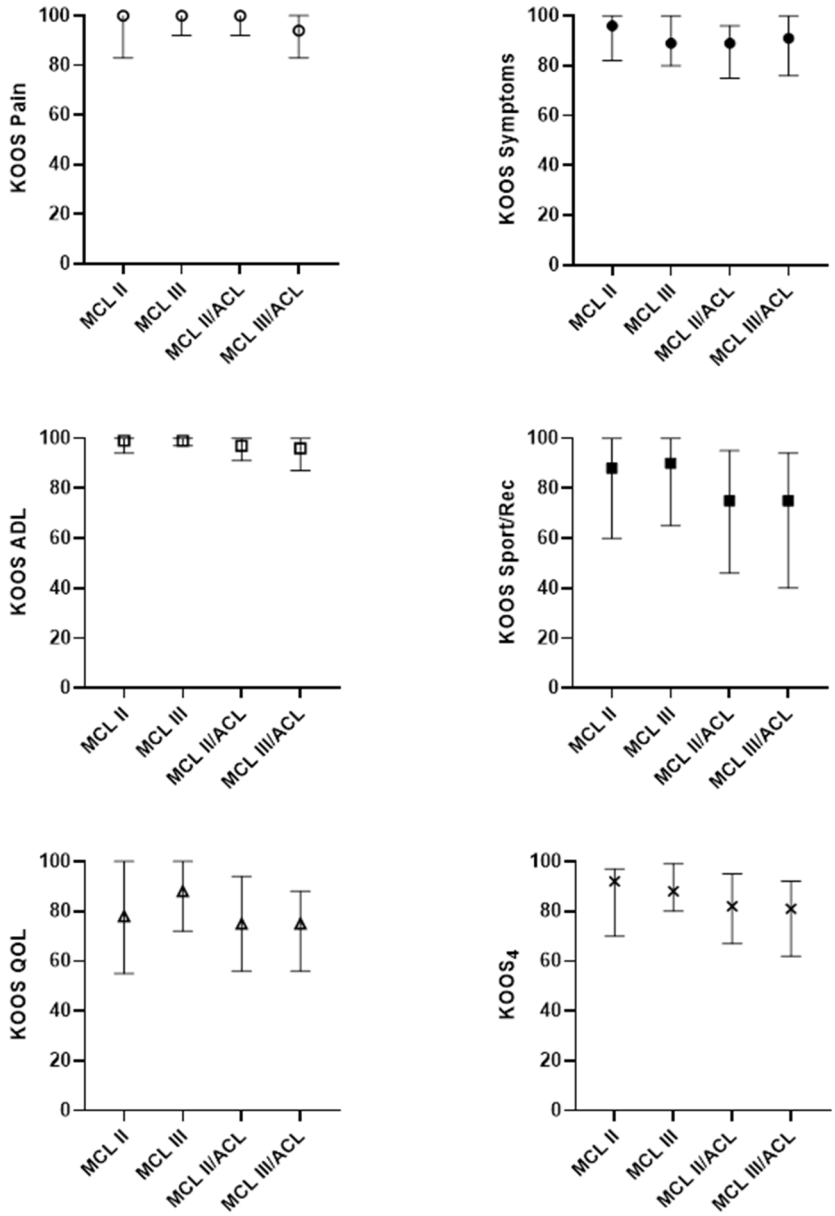

Figure 9. KOOS scores. Median (25th, 75th percentile). ADL (activities of daily living), Rec (recreation), QOL (quality of life), MCL (medial collateral ligament), ACL (anterior cruciate ligament).

Radiographic osteoarthritis appeared more prevalent in the groups with concomitant ACL injury than those without ACL injury (41% vs 25%) although differences between groups were not statistically significant when compared to isolated MCL grade II injury (Table 4).

Table 4. Prevalence of radiographic knee osteoarthritis at follow-up.

Injury type		No ROA	ROA	p value
MCLII (ref)	n (%)	12 (71)	5 (29)	-
MCL III	n (%)	15 (79)	4 (21)	0.71
MCL II/ACL	n (%)	36 (60)	24 (40)	0.57
MCL III/ACL	n (%)	27 (59)	19 (41)	0.56

ROA (radiographic osteoarthritis), MCL (medial collateral ligament), ACL (anterior cruciate ligament), ref (reference group).

The prevalence of residual valgus laxity was highest after MCL grade III and MCL grade III/ACL injuries (36% and 24% respectively) and lowest after MCL grade II and MCL grade II/ACL injuries (6% and 11% respectively). Baseline characteristics, patient-reported outcome and radiographic osteoarthritis prevalence were similar for subjects with and without residual valgus laxity.

Discussion

This is a clinical thesis based on routines established in an effort to improve the diagnosis and treatment of patients with acute knee injuries. These routines were introduced over two decades ago by a group of knee specialists who appreciated the importance of early diagnosis and a co-ordinated, team orientated approach to the management of this group of patients. Despite initial controversy and even resistance from local academic centres to this type of follow-up, similar protocols are now commonplace in Sweden. The heart of the thesis is an evaluation of this diagnostic routine and the treatment protocols associated with it.

The findings in paper I show that clinical examination has an overall moderate sensitivity and specificity in diagnosing ligament injury and LPD after knee trauma as compared to radiologist's MRI report. Orthopaedic knee specialists were almost six times as likely to make a diagnosis in agreement with MRI for those with an ACL rupture compared to an emergency department doctor. Despite a clear trend toward better detection of LPD for knee subspecialists this was not statistically significance. The difficulty of examination of acutely injured knees is highlighted by the proportion of major knee injuries which were not suspected at the initial examination. In the cohort a high proportion of knees with typical MRI signs of acute patella dislocation and ACL rupture were not clinically diagnosed as such. Furthermore, with a major intra- or periarticular injury diagnosed in over 90% of cases [86], this study indicates the significance of hemarthrosis as a predictor of serious joint injury requiring further diagnosis [33,40,84,102]. While it has been suggested that sub-acute clinical examination by an experienced orthopaedic surgeon may be as reliable as MRI evaluation, prior studies on this subject focus almost entirely on ACL injury which clearly does not represent the full spectrum of possible injury [1,61]. Early and correct diagnosis has clinical importance not only for early treatment strategies and for avoiding or worsening secondary associated injuries, but also for proper information and prognosis regarding recovery, and for guidance on return to sports [78,82]. One of the strengths of the study is the consecutive inclusion of patients based on history of acute trauma with hemarthrosis regardless of the degree of suspicion of a major injury which may otherwise have led to patients being missed.

In paper II I identified the agreement between clinical grading of the MCL by an experienced examiner versus MRI grade. The agreement was at least moderate according to Landis & Kochs criteria[63]. This agreement was not as high as another

recent paper on the subject although the authors of this study chose a quadratic rather than linear weighting in their analysis [73].

The results of paper III suggest that larger radiographic posterior tibial translation at follow-up is associated with poorer patient-reported outcome. Despite there being a widely held belief that persistent posterior translation leads to a poorer outcome after PCL rupture this is one of very few studies that found an association with this at long-term follow-up. This may be due to the fact that many previous studies have based their estimation of tibial translation on clinical examination findings rather than radiographic measurement which is more objective [21,89,90,107,108]. It is important to note however that this cohort was small and the confidence intervals wide demonstrating the degree of uncertainty in the results. There are several methods of measuring RPTT in the literature. The Puddu method was chosen as this is reported to be reliable, less painful than stress radiography and can be carried out with standard radiology department equipment [49]. In keeping with previous research there was a high degree regained continuity of the PCL on follow-up MRI 11 years after injury highlighting the ability of the PCL to heal [3,47,109] . A particular strength of the AKP protocol is that it is based on a general population and has a high accuracy for PCL injuries. Many other studies on this subject originate from subspecialist referral centres and there is a higher possibility of undetected cases in the general population. As such this study likely better reflects the true long-term outcome after PCL injury.

Although a number of the injuries sustained were multi-ligamentary we chose not to classify these using a multi-ligament knee injury classification system. The major reason for this is that the commonly used classification systems assume the knee has been dislocated [11,56,104]. While a dislocation will commonly result in a multi-ligament knee injury, a multi-ligament knee injury is not necessarily the result of a dislocation [117]. While we cannot provide definitive evidence of a lack of knee dislocations in the patients followed-up there were no cases of nerve or vascular injury requiring treatment and no patients required emergent surgical stabilisation of their knee that might suggest dislocation. In addition, high-energy trauma and multi-trauma cases generally follow another admission pathway at the hospital. A further reason we chose not to classify multi-ligament injuries in this way is that the classifications are generally anatomic descriptions of injury patterns and do not predict outcome based on the injury pattern present.

In recent years there has been a trend toward recommending operative management, particularly of combined MCL and ACL injuries [34,43], despite a lack of clear evidence that non operative management of grade III MCL injuries results in worse outcome compared to grade II injuries. Paper IV provides further support that isolated grade II and III MCL injuries can be treated without surgery with very few patients undergoing subsequent collateral ligament reconstruction. In addition, patients with combined MCL grade III/ACL injury rarely require MCL

reconstruction and achieve similar outcomes to those with combined MCL grade II/ACL injury at long-term follow-up in all outcomes except the Tegner scale. The presence of a concomitant ACL injury was the clearest factor negatively affecting outcome. The poorest patient-reported outcomes and highest prevalence of radiographic knee osteoarthritis was noted in the group with combined MCL grade III/ACL injury. While this group clearly sustained a more severe knee injury than others in the subgroup analysis they were also, on average older than patients in the other injury pattern subgroups. As such they would be expected to have lower Tegner scores even in the absence of injury although perhaps not quite as pronounced as those found in the cohort [13]. We cannot fully explain the low Tegner scores, however, many patients were in their 30's and 40's at the time of follow-up, an age where family and work commitments often take priority over regular sports participation, particularly competitive. The Tegner scale does name particular sport and activity examples at each level although only a numeric value is recorded which obviously gives limited information on exactly what type of activity the patient is able to perform. In this respect the Activity Rating Scale may have been an appropriate supplementary outcome measure to assess sports related challenges as it records particular aspects of sports performance such as pivoting and cutting which patients with ACL and MCL insufficiency may have difficulties with.

Interestingly, subsequent ACL reconstruction (ACLR) was more common after grade II/ACL injury than grade III/ACL injury. The prevalence of ACLR failure was also higher in grade II compared to grade III injuries. Considering the demographics of the grade III/ACL subgroup, age and activity level may go some way to explaining the lower rates of ACLR and also the associated failure rate. It is possible that the older age of this group could be a factor affecting the decision to offer reconstruction or not of the ACL. Although a large registry study suggested that outcomes of ACLR were improved when the MCL injury was managed operatively the study was limited by the lack of information regarding the degree of laxity present [113]. While biomechanical evidence exists suggesting that strain on the ACL is higher in an MCL injured knee [8,75,96] several other studies have reported satisfactory outcome of non-operative management of MCL injuries in patients undergoing ACL reconstruction [37,38,118]. Further, complications such as post-operative stiffness and arthrofibrosis have been reported to be more prevalent after surgical management of MCL injury in this group of patients [37,77,110,118].

A number of patients are left with a degree of residual valgus laxity after non-operatively managed MCL injury. A potential explanation for residual laxity can be drawn from an earlier animal study which identified that mid-substance gaps heal by scar formation. This scar continued to be structurally abnormal even at long term follow-up [29]. In terms of patient-reported outcomes and prevalence of radiographic knee osteoarthritis however, the outcome of patients with residual laxity was very similar to patients without residual laxity. Residual laxity after grade II injury was also reported by Derscheid and Garrick [24] as well as Indelicato [46] who found that the

majority of patients had a small amount of residual laxity which appeared not to affect their return to sport. Animal studies have suggested that immobilisation has negative consequences on both structural and mechanical properties of both injured and uninjured MCL's [88,121,122]. Our accepted standard of treatment is 6 weeks in a range-of-motion brace allowing full extension, 90 degrees flexion and weight bearing as tolerated. A number of older studies which are still frequently cited utilised complete immobilisation for up to 10 weeks after injury [27,42,46,53,54]. Although it is difficult to compare these directly it should be mentioned that a number of the studies which reported poor outcome for non-operatively managed injuries also utilised long periods of immobilisation [27,53,54]. It is our opinion that this contributes to suboptimal collateral ligament healing and could explain the poor outcomes in these studies.

Limitations

Paper I:

Despite a large cohort collected over a period of 6 years there were very few PCL and high grade LCL ruptures. For this reason, it was not possible to draw reliable conclusions about diagnostic accuracy for these injuries. We considered MRI as the gold-standard for diagnosis. While arthroscopy is still officially considered the gold-standard it has, in practical terms, largely been superseded by MRI. As the vast majority of patients were managed without surgery in the initial phase, we were unable to study the correlation between MRI and arthroscopic findings. As the goal of the study was to evaluate the role of clinical examination in routine practice, a strict, standardised examination protocol and calibrated examiners were not utilised. Although this is theoretically a limitation it also means the findings ought to be generalisable to other routine clinical practice settings. The AKP is not a pathway for patients suffering high-energy and/or multi-trauma and as such some knee injury patterns may not be represented as these patients are managed via another treatment pathway.

Paper II:

While the overall cohort was large, only around a third were assessed by an orthopaedic specialist. Many of the participants in the study presented initially to the emergency department which is generally not staffed by orthopaedic specialists and subspecialists. Of those assessed the majority had either no injury or a grade I injury to the MCL leading to a relatively low prevalence of grade II and III injuries.

Paper III:

There were very few PCL injuries in the cohort highlighting the difficulties with studying such rare injuries. Due to the small sample size, we chose to present comparisons between groups using differences in means/medians and 95% confidence intervals in order to demonstrate the degree of uncertainty associated with the findings. The management of PCL injury remains controversial but in recent years specific PCL braces have gained a high degree of acceptance [3,47,50]. At the time of initial management specific PCL brace treatment was not widespread and as such no patients in the cohort were managed in this way.

Paper IV:

There are a number of injury subtypes which have been described, namely anteromedial rotatory instability, deep MCL injury and distal MCL injury. No patients in the followed-up cohort were identified as having an anteromedial rotatory instability although understanding of this injury pattern is now much more widespread than at the time of patient recruitment. The primary diagnostic criteria for the study were MRI based and the original MRI protocol did not specifically address the questions of anteromedial rotatory instability or deep MCL injury. Distal MCL injuries are considered by some to have a worse prognosis than proximal ones when managed non-operatively [30,119]. Although previous studies have attempted to subclassify MCL injuries based on tear location [83] there is to our knowledge no accepted method of subdividing the ligament in this way based on MRI. We chose, therefore not to explore this.

Conclusions and clinical implications

We found that clinical diagnosis after acute knee injury was relatively unreliable vs findings from MRI even when performed by orthopaedic specialists. As such, we recommend that MRI should be utilised in the evaluation of patients with acute knee trauma with hemarthrosis.

Despite only moderate agreement between clinical and MRI based gradings of the MCL, MRI still provides valuable information regarding associated injuries, MCL injury pattern and possibly the need for early surgery.

Non-operatively managed acute PCL injuries display a high degree of PCL continuity on MRI at follow-up. However, there is a large variation of radiographic posterior tibial translation with higher values being associated with poorer patient-reported outcomes.

Non-operatively managed grade III MCL injuries both with and without concomitant ACL injury achieve largely similar patient-reported and radiographic outcomes to their grade II counterparts at long-term follow-up.

Future perspectives

There is a wealth of information in the acute knee project cohort that is still to be utilised. A study investigating risk of future osteoarthritis across the whole cohort has recently been published. The long-term outcome after ACL injury in younger patients is also a question that could be evaluated with data from this cohort.

The systematic identification and treatment of knee injured patients as per the original acute knee injury protocol is still in use today and could potentially be utilised for further studies to explore the following questions:

- Can intra-articular corticosteroid injection reduce the negative effects of knee injury in the long-term?
- Does outcome differ in PCL injuries treated with and without PCL specific braces?

Due to the low prevalence of PCL and certain collateral ligament injury patterns it is likely that a large multicentre trial would be needed to answer the question of whether operative management can improve outcome in these cases.

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