Symptoms, diagnosis and outcomes in PCL injuries

PhD Thesis

Christian Owesen

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Department of Orthopaedic Surgery

Akershus University Hospital

Institute of Clinical Medicine

Campus Ahus

University of Oslo

Table of contents

Acknowledgements

Abbreviations

ACL	Anterior cruciate ligament
ACLR	Anterior cruciate ligament reconstruction
ADL	KOOS subscale Activities of Daily Living
ALB	Antero lateral bundle of the PCL
CI	Confidence interval
DB	Double bundle
DKKR	Danish ACL reconstruction registry
EQ-5D	EuroQol five dimensions questionnaire
ICER	Incremental cost efficiency ratio
ICRS	International cartilage repair society
KOOS	Knee Osteoarthritis Outcome Score
MDC	Minimal detectable change
MRI	Magnetic resonance imaging
NKLR	Norwegian knee ligament registry
OA	Osteoarthritis

PCL	Posterior cruciate ligament
PCLR	Posterior cruciate ligament reconstruction
PMB	Posteromedial bundle of the PCL
QALY	Quality adjusted life year
QoL	KOOS subscale Knee related Quality of Life
SB	Single bundle
SD	Standard deviation
SKLR	Swedish knee ligament registry
Sport/Rec	KOOS subscale Function in Sports/Recreation
STROBE	Strengthening the reporting of observational studies in epidemiology
TKA	Total Knee Arthroplasty
WOMAC	Western Ontario and McMaster Universities

Included papers

Paper I

An isolated rupture of the posterior cruciate ligament results in reduced preoperative

knee function in comparison with an anterior cruciate ligament injury

Årøen A, Sivertsen EA, Owesen C, Engebretsen L, Granan LP

Knee Surg Sports Traumatol Arthrosc. 2013 May;21(5):1017-22.

Paper II

Patients With Isolated PCL Injuries Improve From Surgery as Much as Patients

With ACL Injuries After 2 Years.

Owesen C, Sivertsen EA, Engebretsen L, Granan LP, Årøen A.

Orthop J Sports Med. 2015 Aug 19;3(8):2325967115599539.

Paper III

Epidemiology of surgically treated posterior cruciate ligament injuries in

Scandinavia.

Owesen C, Sandven-Thrane S, Lind M, Forssblad M, Granan LP, Årøen A.

Knee Surg Sports Traumatol Arthrosc. 2015 Sep 19

Paper IV

Owesen C, Røtterud JH, Engebretsen L, Årøen A

Prognostic Factors for Patient Reported Outcome Following Posterior Cruciate

Ligament Reconstruction

Submitted Am J Sports Med. Awaiting review.

Paper V

Owesen C, Aas E, Årøen A

Health economic aspects in treatment of posterior cruciate ligament injuries

Submitted Knee Surg Sports Traumatol Arthrosc. Awaiting review.

The thesis at a glance

Paper	Research question	Material	Main findings
I	How are the preoperative symptoms in patients with PCLR compared to patients with ACLR	71 patients with an isolated PCL injury from the NKLR	Patients with PCL injuries exhibit worse preoperative knee function than patients with ACL injuries
II	What are the outcomes of PCLR compared to ACLR	71 patients with an isolated PCL injury from the NKLR (The same cohort as in Paper I)	Patients improve as much from PCLR as from ACLR. As a consequence of an inferior preoperative score, patients with a PCL injury end up with an inferior result
III	What are the injury mechanisms and what are the most common	1,287 patients with PCL injury from the NKLR, SKLR and DKRR	More than half the PCL injuries occur in sports. Most of the injuries involve

	concomitant injuries with PCL injuries		concomitant injuries to other ligaments, only 1/3 of the injuries are isolated PCL injuries
IV	Are there prognostic factors for outcomes of PCLR	410 patients with a PCL injury from the NKLR	Patients injured in sports improve more than others following PCLR. Multiligament injuries do not predict a worse outcome in PCL injuries
V	What are the costs of the different treatment options for PCL injuries, and can PCLR be considered cost effective compared to nonoperative treatment	Numbers regarding cost of treating PCL injuries from the authors' institution	As the extra cost of treating PCL injuries surgically is relatively small, PCLR can be considered cost effective.

1 Introduction

1.1 Background

A PCL injury is a serious knee injury, although not as frequently occurring as ACL injuries [4, 81]. Isolated injuries involving PCL can most often be treated nonoperatively [22, 34, 75-78]. As a result of this, little is known about epidemiology and outcomes following surgically treated PCL injuries. In general PCL injuries have been regarded more as a motor vehicle accident rather than a sport injury, which is different from the view in the orthopedic society on ACL-injuries [16, 37]. The literature is limited with low numbers of subjects in most studies and no RCTs comparing treatment options currently available. The knowledge is limited regarding in which setting these injuries occur and which results to expect following surgery. Traditionally nonoperative treatment has been the standard in handling isolated PCL-injuries with no fractures involved [10]. As there has been much focus on ACL injuries, the opposite has been true for PCL injuries. This is probably partly due to the fact the PCLRs are performed in relatively small numbers compared to ACLR and relatively few institutions perform the numbers of PCLRs needed to conduct studies of sufficient quality.

With the introduction of the Scandinavian knee ligament registries in 2004/2005, it has become possible to conduct observational studies on patients undergoing PCLR. The present thesis is a result of a desire to increase the knowledge about treatment of PCL injuries. Conducting studies with focus on the epidemiology, symptoms, costs and outcomes following PCLR is an evidence based approach to gain more

knowledge on these injuries. This is important in order to improve strategies for injury prevention, results after surgery and overall treatment strategies.

1.2 Relevant anatomy

The PCL is the largest and strongest of the knee ligaments and can withstand forces of about 2,000 N according to biomechanical studies [21, 29]. The PCL provides important stabilization to the knee [47, 48, 57]. First and foremost, it provides restraint to posterior tibial translation [10, 23, 39, 48], but it also provides some stability to tibial internal and external rotation [41, 53]. The PCL consists of two intertwined bundles, the anterolateral bundle and the posteromedial bundle – named for their relative femoral insertion areas [4, 43, 47]. This was first described early in the 20th century. The PCL runs from the lateral aspect of the medial femoral condyle, right on the border of the articular cartilage. On the tibia, the attachment site is extra articular, just below the joint line central on the tibia in a coronal view (Figure 1)[48]. The two bundles can be defined from the femoral attachment sites, while it is more difficult to define two separate bundles at the tibial site [4, 11]. The ALB is by far the thicker and stronger of the two [47]. This fact is utilized in SB PCLR, which traditionally has been the most common technique of reconstruction [89]. More recently biomechanical studies have reported that anatomic DB reconstruction gives a better approximation of native PCL kinematics and better stability in objective measures [30, 42, 89].

Figure 1
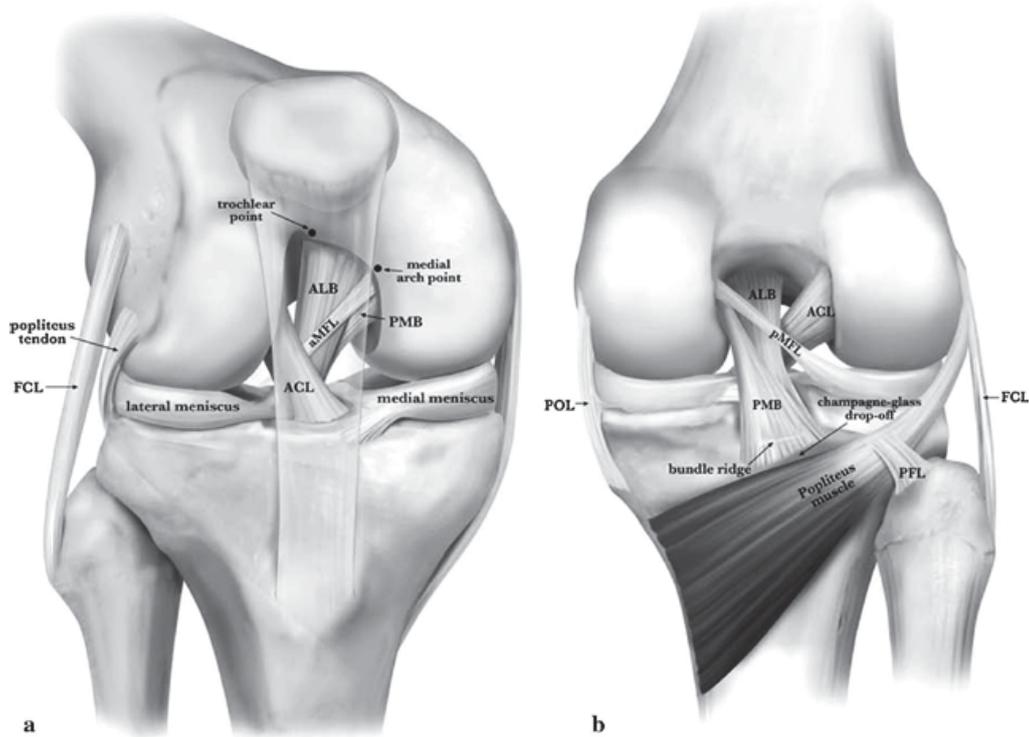
a) Anterior and b) posterior view of the knee (Reprinted with permission from American journal of Sports Medicine, Am J Sports Med. 2013;41(12):2828-2838)

1.3 PCL injury

A PCL injury is considered a rare event compared to ACL injuries. There is a vast span in the reported incidence and prevalence of such injuries which reflects the setting of the reporting. The PCL is reported injured in 1-44% of all knee injuries [14,]

[76, 81]. Traditionally we are told that the main mechanism of PCL injuries is traffic accidents with a direct hit on the tibia from the dash board. Several studies have reported other important injury mechanisms with sports as the most frequent cause [14, 74]. In sports the PCL in typically injured with a direct blow to the anterior tibia during a tackle. This is typically seen in American football and rugby. Other important mechanisms include falling on a flexed knee or rotational traumas. When the PCL is injured in rotation, it is often part of a more complex knee injury with injury to other important stabilizing structures such as the ACL, LCL, MCL, joint cartilage and menisci. In contrast to ACL injuries, PCL injuries are more common in males [16, 79].

1.4 Diagnosis

The symptoms of a PCL tear are not as clear as for an ACL tear. The patient may complain of knee instability, discomfort in the posterior aspect of the knee or unspecific pain. There is frequently no pop-sound or feel [47, 54]. There may also be only minimal joint swelling.

As excellent results have been reported with nonoperative treatment and with or without the use of a brace, it is imperative with an early diagnosis [34, 35, 77]. When the first couple of weeks have past, the healing potential in a close to anatomical position is rapidly declining, although healing still often occurs with an elongated PCL as a result. This is probably a main challenge in treating PCL injuries. The

most accurate physical examination test is the posterior drawer test which has a sensitivity > 90% and a specificity > 99% [13, 46, 69]. Other tests like sag test, dial test and reverse pivot shift test are also useful for detecting an isolated or combined injury (Table 1). If a PCL injury is suspected, the diagnosis is verified by an MRI. MRI has a reported sensitivity and specificity of close to 100% for diagnosing acute PCL injuries [20, 27, 61]. Then additional imaging with stress radiographs should be done. Stress radiographs are useful for providing an objective method of the grade of instability compared to the contralateral knee (unless this knee is also injured) [32, 36, 80]. The injuries can be graded (I-III) where a grade III injury is a total rupture and considered having a lower success rate with nonoperative treatment (Figure 2). If the instability on stress radiographs is measured to be > 12 mm compared to the noninjured side, it is likely that more structures like for instance the PLC have been injured and early reconstruction is then often warranted to avoid a severely unstable knee [43, 47].

Table 1

Sensitivity and specificity of tests for posterior cruciate ligament injuries

Test	Sensitivity	Specificity
Posterior drawer	0.22-1.00	0.98
Posterior sag sign	0.46-1.00	1.0
Dial	Not reported	Not reported
Reverse Lachmann	0.63	0.89
Reverse pivot shift	0.19-0.26	0.95
Varus/valgus stress with 0° knee flexion	0.28-0.94	1.0

Adapted from a systematic review by Kopkow et. Al [46]

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Figure 2
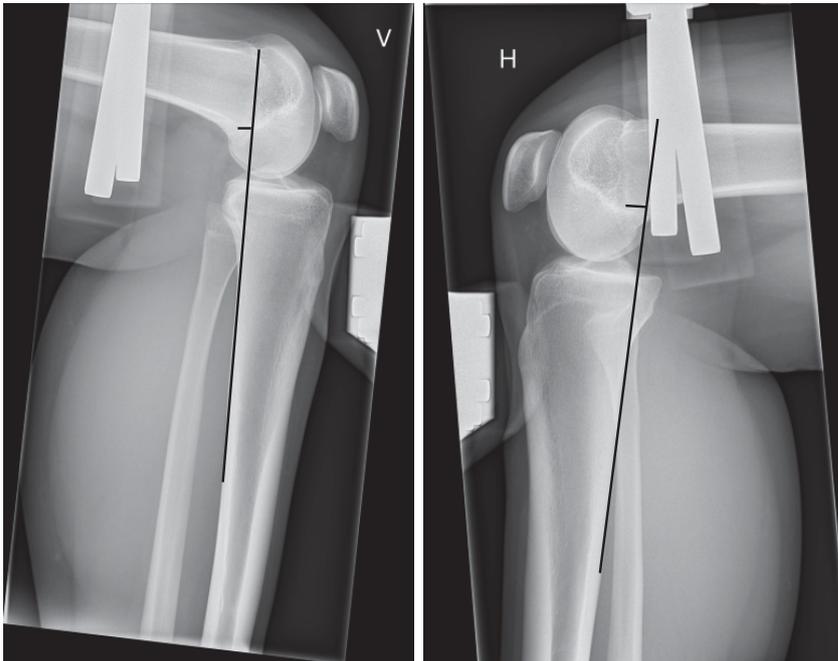
PCL injury right knee with a difference of 12 mm compared to the left (uninjured)

knee with the use of a Telos device® (Austin & Associates, Fallston, MD, USA)

1.5 Treatment

A PCL deficient knee can be left unstable. Although the PCL has an intrinsic

healing capability [47, 60, 75], this healing may occur non-anatomically resulting in an

elongated ligament [22, 34, 52]. This elongated ligament may have small or no functional

value. Nonoperational treatment of a PCL injury commonly includes the use of a

dynamic knee brace and physiotherapist guided exercises for several weeks [35, 49].

Studies report excellent outcomes following such treatment both when it comes to

objective measures and patient reports [59, 75, 76, 83]. Despite this, some patients are left

with an unstable and painful knee with poor function in daily life activities or sports. This can be the result of a subluxation of the knee joint, which is often reported as the knee giving away. The option in such cases is surgical reconstruction. If pain alone is an indication for surgery remains a matter of debate. In the 1980s and even 90s, olecranization of the patella was a common procedure with PCLR. The theory was that transfixation of the patella to the proximal tibia with a pin would provide a restraint to the tibia gliding posteriorly, allowing for a shorter period of immobilization. Olecranization has since been abandoned as the concept has been proved biomechanically less profitable [38, 70]. The method of reconstruction can be single bundle with an attempt to replace the ALB [31, 44, 55, 89]. This has been the most commonly used method in the Scandinavian countries. The graft of choice is most often hamstring autograft. The alternative is anatomical double bundle reconstruction. This can be achieved with autograft, but often involves the use of one or two allograft(s) to avoid several graft morbidity sites. Both methods of reconstruction have been reported to yield satisfactory results [41, 42, 63]. It is so far unclear if one is better than the other [44, 45, 50, 87]. The numbers of patients treated are small in all existing studies. No RCT has been published on the treatment of PCL injuries so far, but DB is becoming more popular as biomechanical studies [42, 89] and some clinical studies [50, 91] show superior results compared to SB reconstruction .

1.6 Outcome

Following a PCL injury, there is a fair chance of returning to preinjury activity level [75-77]. This is true for both nonoperational treatment and after surgical reconstruction [47, 79]. We do however not know how good the results following reconstruction are compared to ACL reconstruction which is more commonly performed. ACL reconstruction is worldwide considered a successful treatment, though the procedure is still being developed. In a longer perspective, patients suffering a PCL injury are at a risk of developing medial and patellofemoral OA [40, 58, 75]. With surgical reconstruction, we attempt to restore knee stability and kinematics. This may reduce the progression of OA development. It is not known which patient categories benefit the most from surgical reconstruction, and we do not know the implication of factors such as age, gender, activity level, concomitant injuries.

2 Aims

We need to put focus on epidemiology, treatment options and expected outcome of PCL injuries in order to inform patients about the injury and what to expect following the different treatment options currently available. This knowledge may also tell us if there is a need to develop new treatment strategies.

2.1 Specific aims

2.1.1 To investigate the preoperative complaints reported by patients with PCL injuries

2.1.2 To investigate outcome following PCLR compared to outcome following ACLR

2.1.3 To look closer at the epidemiology of surgically treated PCL injuries with focus on mechanism of injury and concomitant injuries

2.1.4 To investigate the effect of injury activity and concomitant ligament injuries on patient reported outcome following PCLR

2.1.5 To highlight the cost to the health service provider regarding the treatment of PCL injuries

3 Ethics

Participation in the Norwegian and Swedish registries is voluntary for both surgeons and patients. Patients sign an informed consent, and the NKLR is approved by the Norwegian Data Inspectorate. Similar rules and restrictions apply for the SKLR although informed consent from the patients is not required. In Denmark reporting to DKRR is mandatory for all clinics and informed consent from the patients is not required. Follow-up KOOS questionnaires are collected at set intervals postoperatively and allowed used anonymously for research purposes. All data extracted from the registries are anonymized.

4 Materials and methods

4.1 Knee ligament registries

In 2004 the NKLR was established as the first national knee ligament registry in the world. This was followed by similar registries in Denmark and Sweden. Several registries have since been developed in other countries. The Norwegian registry was developed with an aim of prospectively monitoring the outcomes of knee ligament surgery. The NKLR has been thoroughly described in previous studies [24, 25]. All knee ligament surgery, including revision and other types of reoperations are reported to the registry by surgeons all over the country to the NKLR. Reporting to the registry is voluntary. The surgeon completes a form postoperatively, with information regarding the findings and specifications of the performed procedure – including any concomitant injury to any other ligaments, menisci, joint cartilage, major nerve and blood vessel injury. The patients fill out a KOOS questionnaire preoperatively and at 2, 5 and 10 years postoperatively. Revision surgery, TKA and KOOS are the outcome measures in the registry. The registry contains no clinical information or grading of the PCL injuries. The nationwide report rate to the registry for primary procedures is 86% [92]. For the patient KOOS follow up at two years, the report rate is approximately 60%. The registry has resulted in several important publications in sports medicine. The Swedish and Danish registries started in 2005. The have similar report rates as the NKLR [3, 65]. In addition to KOOS, the SKLR and DKRR both include EQ-5D and DKRR also include Tegner activity score. In Norway

informed consent is obtained from all patients for the preoperative KOOS, whereas

this is not the case in Denmark and Sweden due to different legal requirements [51].

Report rates to the SKLR and the DKRR are similar to the report rate to the NKLR.

4.2 KOOS

The KOOS was developed in the 1990s by Roos et. al. The intention of the KOOS

was to detect changes over time in a population with knee injuries [67]. The KOOS

includes the WOMAC Osteoarthritis Index in its complete and original format. The

KOOS questionnaire is a validated and reliable tool for measuring knee function in

patients with osteoarthritis (OA) and for several types of knee injury including ACL

injuries, meniscal injuries and cartilage injuries [66]. The questionnaire has been used

in populations 13-79 years of age. The use of a validated and reliable tool is

imperative when used to monitor outcomes and changes over time in knee injuries.

The KOOS questionnaire is a self-administered knee function score consisting of 42

questions divided into five different subscales; Pain , other Symptoms, Activities of

Daily Living (ADL), function in Sport/Recreation and knee related Quality of Life

(QoL). The previous week is the time period considered when answering the

questions. According to the official web page, it is recommended to use each

subscale independently when evaluating outcome in clinical studies [67]. Each

subscale ranges from 0 (worst) to 100 (best). The MDC is dependent on the test-

retest reliability of the questionnaire. The more reliable the questionnaire is, the

smaller is the difference that can be detected. In a study regarding knee injuries, the MDC is 6.0-6.1 for Pain, 5.0-8.5 for Symptoms, 7.0-8.0 for ADL, 5.8-12.0 for Sport/Rec and 7.0-7.2 for QoL [9]. A difference of 8-10 points in a subscale is usually considered a clinically relevant effect.

4.3 Study design

Paper I

The study design was a prospective cohort study. There were 10,575 patients registered with a primary ligament procedure in the NKLR from 2004-2010. Of these there were 295 registered PCLRs. 71 (24%) of the 295 were isolated PCL injuries, and these isolated injuries were used for the study. In the study population, there were 35 (49%) males. Median time from injury to surgery was 21.5 months. There were seven (9.9%) meniscal lesions and seven (9.9%) full thickness cartilage lesions. Average age at time of surgery was 27.1 years. The patients were compared to 9,551 patients with isolated ACL injury. Among the ACL patients there 5,458 males (57.1%), median time from injury to surgery was eight months, there were 4,441 meniscal lesions (46.5%) and 650 full thickness cartilage lesions (6.8%). Average age at time of surgery for the ACL patients was 26.2 years.

Paper II

In this paper, the same patient cohort as described in Paper I was used as a basis for the study. All patients (45) with isolated PCL injuries who had completed the KOOS questionnaire two years postoperatively were included and compared to patients (5192) with isolated ACL injuries with completed follow-up KOOS questionnaire at two years. This is a follow-up rate of 65% for the PCL injuries and 56% for the ACL injuries. Demographical data for PCL/ACL patients: males 42.2% vs.51.3%, age 27.7 vs. 28.7, time from injury to surgery 20.5 months vs. 8.0 months, meniscal lesions 11.1% vs. 49.2%, cartilage lesions (ICRS grade 1-4) 31.1% vs. 25.2%.

Paper III

Patients were included from the NKLR, SKLR and DKRR. All patients in the registries with a ligament injury including a PCL injury from 2004-2013 were included. In total, there were 1,287 patients with 585 from the DKRR, 375 from the NKLR and 327 from the SKLR. Mean age at time of injury was 32.7 years. There were 40% females. About 1/3 were isolated PCL injuries. 21% had a meniscal lesion and 26.1% had a cartilage lesion ICRS grade 1-4. About 50% of the patients were injured in sports.

Paper IV

Patients were included from the NKLR. All patients with a registered PCL injury from the years 2004-2013 with a completed KOOS questionnaire two years postoperatively were included. 410 patients were registered with a PCL injury in this period. 252 patients (61.3%) had completed the KOOS at two years follow-up. Mean age at surgery was 35.0 years. There were 112 females (44%). 137 patients (55%) were injured in sports. Median time from injury to surgery was 12.0 months. 173 patients (69%) had a concomitant injury to another knee ligament. 53 patients (23%) had meniscal lesions and 99 (39%) patients had a cartilage lesion ICRS grade 1-4. 172 patients (68%) had their PCL reconstructed with a hamstring autograft.

Paper V

The study was conducted as a cost analysis of the different aspects of treating PCL injuries. Cost per patient treated was divided into three categories based on current common treatments; nonoperational and two groups of surgical reconstruction utilizing either SB or DB technique. For all groups, cost was calculated based on necessary equipment for conservative treatment and the cost of rehabilitation with a physiotherapist based on guidelines given by the Norwegian national physiotherapist association. For the two groups treated surgically the cost of the surgery was added. Then we calculated cost per QALY gained and calculated the cost efficiency of surgical treatment compared to nonoperational treatment.

4.4 Statistical analysis

Q-Q plots were used to check if the data were normally distributed, before analyses with the requirement of normally distributed data were performed.

Crude mean KOOS scores were estimated for the different patient categories in paper I and IV. Linear regression analyses were used to determine the effect of PCL versus ACL injuries (Paper 1) and the effect of activity at time of injury and concomitant ligamentous injury (Paper IV). Based on current literature and clinical assumption, the variables sex, age (continuous variable), time from injury to surgery (continuous variable), concomitant meniscal and cartilage injury, concomitant neural/artery/tendon injury (Paper IV) and type of PCL graft (Paper IV) were considered as possible confounders and predictors for patient-reported outcome in the multivariate analysis. The multivariate analysis was done with the mentioned factors of interest as independent variables and each of the KOOS subscales as the dependent variable. Differences were considered statistically significant for p values <.05. In Paper II, the data at two year follow-up were compared to what was found in Paper I. The CIs were calculated based upon paired sample t-tests. Then the changes for the PCL patients were compared to the relative changes for the control group (ACL patients). In Paper III, a simple descriptive analysis was performed in SPSS and prevalence in the respective countries was calculated based on population numbers from Wikipedia.

All data were presented as means with SD, medians with range, percentages and ratios according to what was considered adequate by the authors. All crude mean KOOS scores and regression coefficient estimates (βs) are presented with 95% CIs. The Wilcoxon rank test was used when comparing time to surgery and age in the ACL and PCL groups (Paper I). The chi-squared test was used when comparing prevalence and categorical data. Correlation was calculated using Person's correlation coefficient.

The software package R was used for the statistical analyses in Paper I and II (http://www.R-project.org). Statistical analyses in Paper II-IV were performed using IBM SPSS Statistics for Windows, version 21.0 and 22.0. Armonk, NY: IBM Corp. software. (Paper II with both R and SPSS).

5 Results

Paper I

The preoperative KOOS in the PCL group (n = 71) and ACL group (n = 9,649) was significantly different for the subscales Symptoms (mean difference, -8.4; 95 % CI: -12.8 to -4.0), Pain (mean difference, -15.9; 95 % CI: -20.3 to -11.4), ADL (mean difference, -12.9; 95 % CI: -17.4 to -8.4), Sport/Rec (mean difference, -15.9; 95 % CI: -22.6 to -9.3), and QoL (mean difference, -7.9; 95 % CI: -12.4 to -3.5). The primary isolated PCL-reconstructed knees had a median time from injury to surgery of 21 months in comparison with 8 months for ACL injuries. The ACL-injured knees had more concomitant injuries (meniscus and full-thickness cartilage lesions) than the PCL-injured knees.

Paper II

The delay to surgery was significantly longer for PCL patients compared to the ACL patients (median 21.5months vs 8.0 months). Most surgeries were performed using single bundle hamstring graft for both PCL and ACL reconstruction. PCL reconstructed patients had an improved patient reported knee function postoperatively measured by KOOS at two years with improvement in all KOOS subscales as follows; Pain: 15.1, CI (8.5-21.8), p<0.001. Symptoms: 0.9, CI (-6.6-8.3), p=0.82. ADL: 13.2, CI (6.6-13.9), p<0.001. Sport/Rec: 20.7, CI (11.8-29.4),

p<0.001. QoL: 26.6, CI (18.9-34.2), p<0.001. The reported results for ACL patients were; Pain: 10.5, CI (10.2-11.5), p<0.001. Symptoms: 5.1, CI (4.1-5.2), p<0.001. ADL: 8.1, CI (7.7-8.6), p<0.001. Sport/Rec: 23.0 CI (22.2-23.8), p<0.001. QoL: 31.7, CI (31.0-32.4), p<0.001. The increments in KOOS for the PCL patients are similar to those of the ACL patients. For the KOOS subscale pain the improvements was larger than for ACL treated patients but no significant difference was found.

Paper III

Average age of the treated patients was 32.7 years. Of the included patients 33.3% were female. Depending on definition, 26-37 % of the injuries treated were isolated PCL injuries. PCL injuries were most commonly encountered in sports, which generated 35.4% of the total amount of PCL injuries in the study population. Soccer was the sport with the highest number of injuries with 13.1% of the injuries. Cartilage lesions occurred in 26.1% of PCL injuries, meniscal lesions in 21.0%, minimum one other additional ligament was injured in 62.2%. The patient populations in the respective countries are comparable with regards to the mentioned variables.

Paper IV

In our material, patients injured in sports activities improved more from surgery than patients injured in traffic accidents or other activities (p<0.001) measured by KOOS. The improvement is statistically significant and clinically relevant with a difference of more than 10 points for each of the subscales except for the symptoms subscale. Those with multiligament injuries have similar KOOS scores as those with isolated PCL injuries at two years, except for the Sport/Rec subscale where the patients with isolated injury on average score 7.9 points higher (p=0.042) in the unadjusted analysis. This difference is neither clinically relevant, nor is it statistically significant in the adjusted analysis (Table 3 and Table 4). The delay to surgery was longer for the isolated injuries. Injuries to the menisci or cartilage is more frequent among the multiligament injuries (p<0.001). Apart from that the isolated injuries and multi ligament injuries are similar with regards to age and sex. Concomitant injuries to either menisci or cartilage do not affect the patient reported outcome in our material.

Paper V

The average calculated cost of nonoperative treatment was €3382. Incremental cost for SB PCLR was 154% and another 61% for DB PCLR, given that the preoperative rehabilitation program is of the same length and intensity as that for the nonoperatively treated patients. The additional cost of reconstruction on average equals the cost to society for three (SB) or six (DB) weeks absence from work in

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Norway. The allografts, material for extra fixation and time in surgery are the factors differentiating cost of the two surgical treatment options. In addition to the cost related to surgery, there is a cost of postoperative rehabilitation for both the SB and DB groups compared to that of the nonoperatively treated patients (Table 2). The additional cost for SB translates to a relatively low gain in QALYs (threshold €70,000 - suggested by Norwegian health authorities). Given an expected gain in KOOS QoL of 27 points, this provides an ICER score of 365. Adding the additional cost for DB reconstruction, this translates to another relatively low incremental gain in QALYs (0.074), but to achieve a similar ICER score with DB over SB PCLR, this requires another incremental gain in KOOS QoL of 28 points.

6 Discussion

6.1 Methodological considerations

6.1.2 Study design

Registry data was used as basis for Papers I-IV of the thesis. Registry data has been widely used in knee ligament research since the development of knee ligament registries in the Scandinavian countries in 2004-2005. The knee ligament registries were developed following success with the national arthroplasty registries that were developed in the 1970-80s. Registry studies are now considered an important part of the research in the area of knee ligament injuries [12]. Such studies have the advantage of making it possible to conduct relatively large cohort studies which in turn can be used to detect factors associated with good or poor outcomes. For monitoring PCLR, registry studies have the advantage of evaluating relatively large numbers of such procedures where an RCT would take decades to gather the same number of patients. With registry studies we also avoid or have limited selection bias.

The four registry studies included in the current thesis were based on observational study design. As with other study designs there are weaknesses related to these types of study. One main focus has been bias related with the reporting of data. Observational study design is considered well suited for answering epidemiological research questions if the data is reported in concurrence with the STROBE guidelines [86]. A report from the Cochrane collaboration in 2014 reveals that observational studies are very similar in results reported by similarly conducted

RCTs [5]. In papers I, II and IV the research question is regarding the preoperative KOOS scores or outcome following treatment of PCL injuries. RCTs are considered the gold standard for answering the questions of effectiveness of an intervention. There are some limitations to using registry data. First the data has been precollected and therefor may be misclassified. Some data may also be missing and how missing data is handled is a topic of discussion. There is also the problem with clinically irrelevant differences becoming statistically significant when analyzing sufficiently large numbers [82]. For registry data to be useful for research studies it is also important with good compliance from the doctors and patients when it comes to reporting data. Report rates and follow-up are key issues.

As mentioned above, an RCT for a relatively rare event like PCLR would require a very long time to conduct. It would also have the disadvantages of being expensive and probably include a selected patient population, leading to problems when trying to generalize the results.

In paper III, the research question is strictly epidemiological, dealing with injury activity leading to PCLR and the occurrence of concomitant knee injuries.

Paper V is a cost-utility analysis dealing with the cost of treating PCL-injuries nonsurgically and surgically in Norway. Standard methods in health economic analysis utilizing cost effectiveness measures have been applied. Health economy analysis is increasingly relevant in a public health care setting were we are able to treat more conditions than before with sometime very expensive treatment options. When developing new treatment strategies, it is important knowledge if the new

measure yields results that are not in contrast to the eventual increase in cost. Considering PCLR which has inferior results compared to ACLR, it is highly relevant to develop better methods of reconstruction, but simultaneously it has the potential of increasing the treatment costs.

6.1.2 Subjects

In Papers I, II and IV patients were included from the Norwegian national knee ligament registry. In papers I and II, only patients with isolated PCL injuries were included. In paper IV all patients with a knee ligament injury including a PCL injury were included. In Paper III all patients registered with a knee ligament injury including a PCL injury in the Scandinavian countries 2004-2013 were included. The national registries have an inclusion rate of about 85-90 % of all primary ACLRs [3,92]. The inclusion rate for PCLR is unknown, but should be similar to the ACLR rate as the patients are treated at the same institutions and by the same surgeons. This ensures representation of a wide range of surgeons, hospitals and patients, which in turn should make the findings of the relevant registry studies applicable to a large group of patients. However the populations should be compared before generalizing the findings from one study population to another. It can also be argued that for such rarer events as isolated PCLR, hospitals or surgeons with low numbers of these procedures probably affect the outcomes negatively. When it comes to the Scandinavian countries, Paper III reveals comparable characteristics of patients

between the three different registries. This is in correlation to what has been shown in a previous study [26].

In Paper I the number of included patients (71) might seem low when comparing to almost 10,000 ACLRs. This was, however, the highest number of included isolated PCL injuries in a published study at the time of submission.

In Paper II the number of included patients is even lower (45) due to loss to follow up. One might argue that this is a highly selected population and that the results might be influenced by selection bias and hence not transferable to larger populations. In general there is a problem with loss to follow-up in the registries. However the loss to follow-up is lower for PCL-injuries compared to ACL-injuries. A previous study has shown similar characteristics between patients with follow-up data and those lost to follow-up in a knee ligament registry [51]. It has also been shown in other fields of medicine that the patients lost to follow-up have the same characteristics as the rest of the population [73, 84].

In paper III all PCLRs registered in the Scandinavian registries in the years 2004-2013 have been included. This represents 1,287 patients which is a very high number in the context of PCL research. Although the patient populations from the different registries are comparable, there are some differences in the preferred graft for reconstruction and the incidence of PCLRs in the respective populations. A weakness of these data is that the registries currently only include those treated surgically. A majority of PCL-injuries are probably still treated nonoperatively or go

unrecognized. The generalizability of the results in Paper III should therefore be interpreted cautiously when considering also nonoperatively treated PCL-injuries.

In paper IV all PCLRs (373) registered in the NKLR 2004-2013 were included. This is again a relatively high number of PCLRs compared to existing studies. The loss to follow-up is again a consideration when interpreting the results. The loss to follow-up rate is higher among the multiligament injuries. There may also be a difference in registration rate between the group with isolated PCL injuries and the group with multiligament injuries. This can affect the results in either direction. There is a higher proportion of males injured in other types of activity than sports and a higher proportion of males with multiligament injuries. This may also affect the results in either direction if there is a difference in outcome between sexes.

In Paper V the basis of the study with regards to KOOS score is similar to Paper II. The same considerations regarding loss to follow-up must therefore be made in context of the QoL scores.

6.1.3 Outcome measures

In papers I-IV the only outcome measure is KOOS. This has certain limitations when interpreting the results. In the NKLR, revision rate is very low for PCLR and the number of conversions to TKA is currently too low to provide reliable data, but both are interesting parameters for future studies. It would be highly interesting with objective measures like stress radiographs, functional tests, clinical examination and

data from an arthrometer. This information is in part available from the Danish

registry [64] and should be an aim for future registration in the NKLR. The problem

with additional information is of course that it demands more resources and that it

might impair the follow-up rate further if the patients experience this as an extra

burden. In a longer perspective (5-10 years) regular radiographs is interesting

considering the fact that PCL-injuries predispose for patello-femoral and medial OA

of the knee [2, 17, 58, 75]. There are also several (more than 50) questionnaires available

for evaluating knee function. The most frequently used include the IKDC, Lysholm,

Cincinnati knee score and KOOS. These scoring tools have been validated and

tested to be reliable for evaluating several types of knee injuries. These

questionnaires also have similar properties although one score may be better suited

than another for certain subgroups of patients and injuries [28]. The number of knee

scores available may reflect the lack of one universally applicable knee scoring tool

that effectively gives a good evaluation of several types of knee injury and at the

same time is well suited for monitoring short and long term outcome following such

injuries. KOOS is still the questionnaire chosen for the Scandinavian registries and

is generally considered both reliable and valid for several types of knee injuries

including ligament and meniscal injuries.

The KOOS questionnaire is a self-administered knee function score that consists of

42 questions divided into five different subscales: Pain, Other Symptoms, Activities

of Daily Living (ADL), Function in Sports/Recreation (Sport/Rec) and Knee-related

Quality of Life (QoL). It was developed in the 1990s by Roos et al. [67]. The KOOS

includes the WOMAC Osteoarthritis Index in its complete and original format, and

it is a validated and reliable tool for measuring knee function in patients with osteoarthritis (OA) and for several types of knee injuries, including ACL injuries, meniscal injuries and cartilage injuries [66]. Each subscale ranges from 0 (worst) to 100 (best). As one might expect, the three first categories are probably best suited for monitoring long term outcome as osteoarthritis is a long term process [85]. The two latter subscales (Sport/Rec and QoL) are usually the most responsive in evaluating knee injuries [9]. Given data from a large cohort of patients, a small possible difference in score might be found statistically significant. This should be considered when making conclusions based on outcome scores. A more relevant question is if the difference is clinically relevant – i.e. what is the minimally clinically detectable change in score?

A difference of 5-8.5 points in each KOOS subscale is usually considered to represent a clinically relevant effect in an injury setting [9]. In the current papers, the calculation of each subscale score and the treatment of missing data were performed according to the Roos et al. guidelines.

The KOOS has certain limitations when evaluating knee ligament injuries over time. The symptoms subscale is not developed with ligament injuries in mind. I t might not detect important complaints of these patients. One such example is that there is no question about a feeling or fear of the knee giving away. This is perhaps one of the most important factors when considering treatment with ligament reconstruction [18, 33, 47, 72, 88]. Another consideration is that there is no means available to monitor the effect on subscale scores of changes in activity level over time. A high performance athlete may have lower demands for function in Sport/Rec at a follow-up compared

to time of injury if he or she is no longer a high level athlete. This again may have an effect on the QoL subscale.

In paper V standard accounting methods have been applied. The term QALY is defined by one year of life lived in perfect health equals one QALY (1 year of life x 1 utility) and that a year lived in less than perfect health is less than one QALY. To determine the QALY value we multiply the years lived by the state of health. One year of life lived in a situation with utility 0.5 (e.g. bedridden) equals 0.5 QALY. QALY can then be incorporated with medical costs expressed as cost per QALY. This parameter can then be used to compare the cost-effectiveness of a treatment [62].

The outcome measure ICER was used when evaluating the cost effectiveness of the different treatment options. ICER is a statistical tool used in cost effectiveness analysis to summarize the cost-effectiveness of a health care intervention. It is defined by the difference in cost between two possible interventions, divided by the difference in their effect. It represents the average incremental cost associated with one additional unit of the measure of effect. The ICER can be estimated as:
Incremental cost-effectiveness ratio (ICER) = $(C_1 - C_0) / (E_1 - E_0)$,
where C_1 and E_1 are the cost and effect in the intervention group and where C_0 and E_0 are the cost and effect in the control care group. Costs are usually described in monetary units, while effects can be measured in terms of health status or another outcome of interest. A common application of the ICER is in cost-utility analysis, in which case the ICER is synonymous with the cost per QALY gained [6].

A concern is that questionnaires commonly used when estimating quality of life measuresfor QALY calculations are not available from the NKLR. There are some problems associated with the QALY term. One may get conflicting results when different questionnaires are used as basis for the calculations [8] and even when using different versions of the same questionnaire [1]. This may in turn produce relevant differences in ICER score. In the absence of EQ-5D or SF-36 data, it can be argued that KOOS QoL is a highly relevant parameter in this setting as it is a direct quality of life associated measure. An even more appropriate basis for calculating quality of life assessments would be possible with a scoring tool specifically developed for knee ligament injuries or even exclusively for PCL-injuries as KOOS has the previously mentioned limitations.

6.1.4 Statistical analysis

In papers I and IV, multiple regression analysis has been used. The major problems associated with this type of analysis is controlling for the most relevant confounders. It is not possible to control for all confounders. The confounders that from experience most likely to affect the results must therefore be chosen. There are several ways of choosing confounders. The most relevant confounders from the authors' view for the respective studies were chosen. This was done in both papers (I and IV) based on relevant existing literature and clinical experience. This is a type of forward selection of confounders and is a recommended method of choosing

possible confounders [19]. Preoperative KOOS was not included as an independent variable in the multiple regression analyses for two reasons. First, the preoperative KOOS score was considered a variable on the causal pathway between the exposure of interest (injury activity and concomitant ligament injury) and the outcome (KOOS at 2-year follow-up). Adjusting for preoperative KOOS would then have led to an underestimation of the effect of injury activity and concomitant ligament injury [56]. Second, controlling for preoperative KOOS would bring extra focus on the effect of the PCL reconstruction on patient-reported outcome, rather than the effect of the injury activity and concomitant ligament injuries [56]. A t-test is not an appropriate tool as the KOOS subscale scores investigated are not normally distributed.

In Paper II, paired samples t-test was used as basis for the confidence intervals when comparing the pre- and postoperative KOOS scores. T-test is considered the most robust statistical method when comparing means of two samples [19]. The paired sample t-test assumes normality of the sampling distribution of the differences between the tested scores. This has been checked for with Q-Q plots and the Shapiro-Wilks test. The alternative would have been to use a regression model. This would probably have generated similar but less robust results. With the use of a regression model we get mean KOOS QoL scores of 52.4 versus 53.0 (t-test) for PCL and 66.6 versus 66.0 (t-test) for ACL. All fall within the respective Cis from either analysis.

The use of a regression model would on the other hand provide us with a lower loss to follow-up if a matched pair of each KOOS subscale score is not required. This would look better in the presentation of the results with a loss to follow-up of 31%

versus 37%. This advantage is however clearly outweighed by the use of a better statistical method.

In paper III, a simple descriptive analysis was performed. The chi-square test was used when comparing prevalence and the categorical data. The chi-square test is used to examine if there is a relationship between two categorical variables. It compares the observed frequency to what we expect to find in those categories by chance. One problem of the test is that the accuracy is dependent on the size of the sample. This is because a larger size is closer to a true chi-square distribution than a smaller sample size. Another problem is that the test result is a matter of interpretation as to what is considered a strong correlation.

6.2 Results

In the NKLR there are about 40 ACLR per PCLR registered. Time to surgery is about three times as long for patients with a PCL injury. The preoperative KOOS QoL score is lower for the patients with a PCL injury and concomitant injuries are common.

6.2.1 Prevalence, concomitant injuries and injury activity

In paper III we found that 1,287 PCLRs were performed in the Nordic countries from 2004-2013. The ACLR to PCLR ratio in the same period was about 50:1. About 1/3 of the PCLRs was done following an isolated PCL injury. About 2/3 of

the treated patients were men. The most frequent associated injury was injury to the ACL (56%). A meniscal lesion was seen in 21% and a cartilage lesion in 26.1%. The activity most frequently leading to a PCL injury was some type of sports (35%).

It is important to keep in mind that these numbers reflect those patients treated surgically. Considering the probability that most PCL-injuries are treated nonoperatively, the distribution of concomitant injuries and injury mechanisms may differ from the whole group of PCL-injuries. There is also the question of the severity of the meniscal or cartilage injury. Some of the meniscal lesions are minor and either left alone or resected whereas others are treated by reinsertion with some type of suture. Cartilage lesions can be graded according to depth and size and there is a big gap in the severity of such lesions. Some may be small and superficial and insignificant impact on KOOS score or the development of OA while some again may be in the opposite end of the scale. Grading of the lesions has not been performed in studies II and IV where in Paper I only ICRS grade III-IV lesions were counted.

The ACLR to PCLR ratios are about the same in Norway and Denmark, but in Sweden relatively fewer patients are treated surgically for a PCL-injury. Why this is remains a matter of speculation. Two theories may be that Sweden has a higher threshold for PCL reconstruction or that there is an underreporting of such procedures to the registry.

There are relatively a higher proportion of men among the PCLR patients. This can be explained by traffic accidents and motorsports contributing to about ¼ of the

PCL-reconstructions. There and more men injured in traffic and there are very few women in motorsports.

The activity leading to the injury is most commonly sports or some leisure activity like outdoor hiking, jumping or falling. This group accounts for > 50 % of the injuries. This is a higher number than what is found in some other studies. In such context, it is important to consider the study population. Other studies on the topic are often conducted at a single center, where the Scandinavian registries reflect patients treated all over the respective countries.

6.2.2 Preoperative scores

In Paper I we showed that patients undergoing PCLR have inferior KOOS scores as compared to patients undergoing ACLR (Figure 1). The QoL subscale score is about 30. Compared to the ACL patients, the score in each of the subscales was 8-18 points lower. We do not know why nonoperative treatment is unsuccessful in some patients with isolated injuries. Part of the reason may be because of the nature of the ligament rupture which fails to heal or heals in an elongated fashion. A factor in this could also be that the injury is not recognized early enough for a brace to have the desired effect [34].

There has been claimed that there is a higher threshold among surgeons for doing PCLR compared to ACLR [15, 47, 90]. This might be part of the explanation why the PCL patients have a lower preoperative score and wait longer from injury to surgery.

45

On the other hand, 21 months from injury to surgery is a long period and a QoL score of 30 is low. This is a clear indication that we should operate more PCL-injuries earlier following injury. Although we have not found a close relation between time to surgery and preoperative KOOS scores in our material, this may be due to a statistical type II error and such a correlation may exist. A QoL score of 44 is perhaps an appropriate guideline for when surgery is definitely indicated as this value has previously been considered to represent a failed knee reconstruction [7]. Furthermore, one should probably be able to decide that surgery is required within one year of the injury as studies on the ACL has showed increased risk of meniscal and cartilage lesions waiting longer than one year with reconstruction [68]. A recent study shows less risk of long term OA in ACL injuries treated with surgical reconstruction [71, 72]. This may also be the case with PCL injuries and hence be an argument for ligament reconstruction.

6.2.3 Postoperative results

In paper II we found that the increase in KOOS score for all subscales was 1-27 points (Figure 3a), with the most significant increase in the Sport/Rec (21 points) and QoL (27 points) subscales. The increases are comparable to the corresponding increases for ACLR patients. This implies that the PCLR patients end up with lower KOOS scores than the ACLR patients as they have inferior preoperative scores. ACLR is generally considered a success. As the improvement in outcome following

PCLR is similar, this should also be considered a success. There is a problem related to this, and that is the fact that the Sport/Rec and QoL subscale scores are very far from a reference population (about 40-50 points below). This clearly indicates that there is room for improvement. It is suggested to reduce time from injury to surgery, make a better selection of patients, and improve the methods of reconstruction and the rehabilitation protocol.

6.2.4 Predisposing factors with effect on outcome

In paper IV we showed that injury activity is important for outcome (Figure 3b). A patient injured in some type of sports, scores significantly higher in the most relevant KOOS subscales than patients with other types of activity at the time of injury. Outcome following surgical treatment is highly dependent on patient selection. This again implies that we should have a lower threshold for PCLR in patients injured in sports and perhaps still be cautious about PCLR in patients with other injury mechanisms.

We also showed that patient reported outcome is not dependent upon if the injury is an isolated injury or a multiligament injury (Figure 3c). This is for the authors surprising. A multiligament injury is obviously a more serious injury than an isolated one as more ligaments are injured. In addition there is the fact that there are more injuries to other structures. There are at least two issues related to this; one is that the long term may be different. Another is the possibility of a type II error as

the numbers not that large. Apart from that, this suggetst that the PCL is the decisive

structure for outcome in multiligament injuries. It also reflects the main finding in

Paper II.

Figure 3
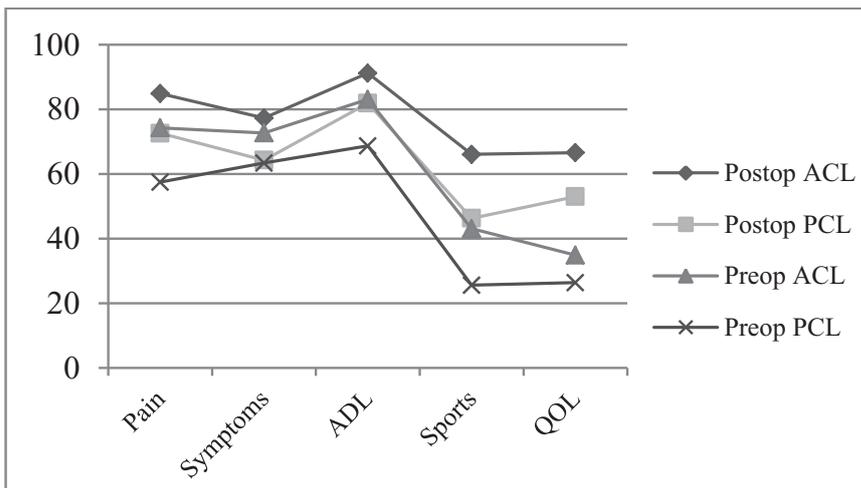
a) Pre- and postoperative KOOS scores
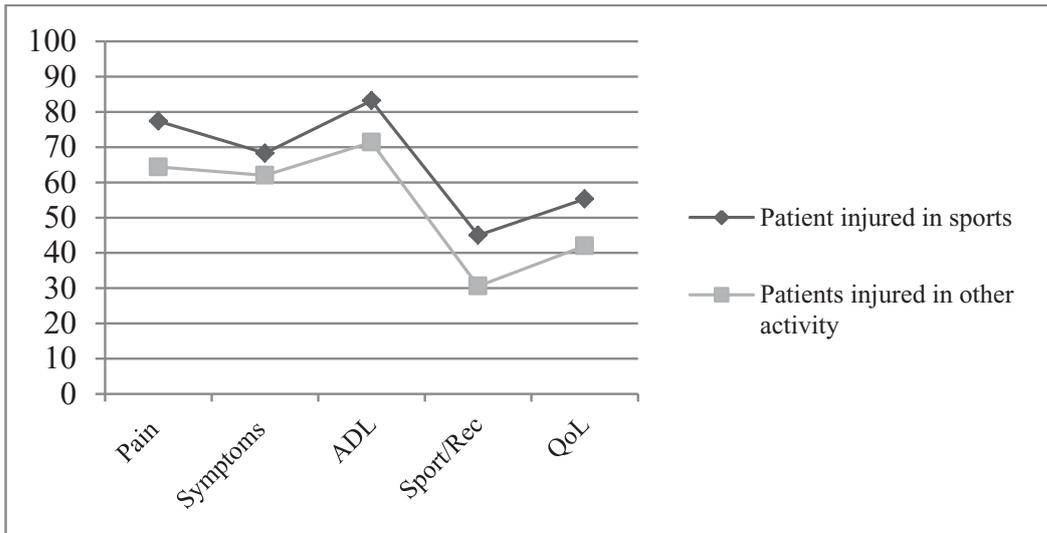
b) KOOS scores by injury activity two years postoperatively
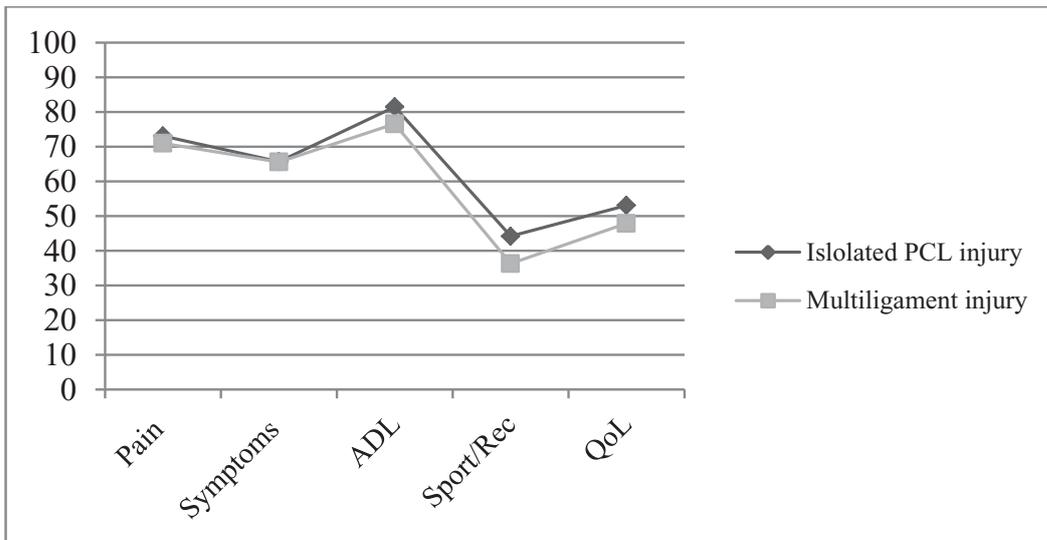
c) KOOS scores two years postoperatively

6.2.5 Economical aspects

Treating PCL injuries surgically adds a cost to non-operative treatment. Principally there are to different approaches to surgical reconstruction, single- and double bundle reconstruction. Double bundle reconstruction adds treatment cost over single bundle as the procedure requires an extra amount of time in surgery and the use of extra grafts and fixation material for reconstruction. Single bundle reconstruction is more cost effective than double bundle reconstruction with a cost equaling a gain in QALY of 0.074 for single and 0.149 for double bundle reconstruction, given a threshold of €70,000 per QALY (current suggestion by Norwegian health authorities). This represents a relatively low cost and indicates that both SB and DB reconstruction are good treatment options. We have previously discussed the need of improvements in methods of reconstruction and with this in mind it is not difficult to defend picking the more expensive DB reconstruction as the cost is not overwhelming compared to the alternative.

7 General conclusions and clinical implications

PCL-injuries are most commonly encountered in sports. It is important to recognize these injuries early to ensure optimal treatment. For isolated injuries this means within the first couple of weeks for a brace to have the desired effect. For multiligament injuries an early diagnosis is important to decide when to operate and to reduce time before start of rehabilitation. Those treated with surgical reconstruction on average have worse preoperative knee function and report worse outcomes as compared to ACL injuries. Those injured in sports have a favorable outcome compared to others. All this can be taken into consideration when opting for reconstruction in isolated PCL injuries and it is useful as patient information regarding what to expect following treatment. There is a relatively small extra cost to society when deciding on DB reconstruction over SB. Until data from an RCT comparing the two available methods is available, the method of reconstruction should be left to surgeon's preference as biomechanical cadaver studies have shown superior results for DB reconstruction.

8 Future perspectives

I. There is a need to investigate why the time from injury to surgery is almost three times as long for PCL injuries compared to ACL injuries. This time should be reduced

II. An RCT comparing SB and anatomical DB reconstruction is warranted and should probably be done as a multicenter study or perhaps as a registry study

III. Although already comprehensive, there is a need for more data in the NKLR. This includes data on patients treated nonoperatively, some sort of QoL measure like EQ-5D and specifically regular and pre-/postop stress radiographs for PCL injuries.

IV. A longer (5-10 years) follow-up of outcome study following PCLR is warranted and one should probably strive to achieve a lower loss to follow-up rate.

V. Improved rehabilitation might also help to restore knee function better in these patients. More physiotherapy research is warranted as existing literature is limited.

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II

Patients With Isolated PCL Injuries Improve From Surgery as Much as Patients With ACL Injuries After 2 Years

Christian Owesen,*[†] MD, Einar Andreas Sivertsen,[‡] MD, PhD, Lars Engebretsen,[§‖¶] MD, PhD, Lars-Petter Granan,[#**††] MD, PhD, and Asbjørn Årøen,[†] MD, PhD
Investigation performed at the Department of Orthopaedic Surgery, Akershus University Hospital, Lørenskog, Norway

Background: Reports on outcome after posterior cruciate ligament (PCL) reconstruction often contain both isolated PCL and combined knee ligament injuries. This makes it difficult to conclude on the outcome after reconstruction of isolated PCL injuries.

Purpose: To investigate the outcome after PCL reconstruction in patients with an isolated PCL injury and to compare this with the outcome of patients treated with reconstruction after isolated anterior cruciate ligament (ACL) injuries.

Study Design: Cohort study; Level of evidence, 3.

Methods: Seventy-one patients with an isolated PCL injury that was reconstructed surgically and who had registered in the Norwegian Knee Ligament Registry between 2004 and 2010 were included in this study. Patients with isolated ACL reconstructions (n = 9661) who had registered in the same period were included for comparison. Knee Injury and Osteoarthritis Outcome Score (KOOS) was used as the patient-reported outcome measure. Preoperative and 2-year postoperative KOOS scores were compared. Changes in KOOS score reported by the PCL patients were compared with changes reported by the ACL patients.

Results: At the 2-year postoperative follow-up of the PCL-reconstructed patients, the patient-reported outcome was improved, measured by KOOS as follows: pain, 15.1 (95% CI, 8.5-21.8; $P < .001$); symptoms, 0.9 (95% CI, –6.6 to 8.3; $P = .82$); activities of daily living, 13.2 (95% CI, 6.6-13.9; $P < .001$); sports, 20.7 (95% CI, 11.8-29.4; $P < .001$); and quality of life, 26.6 (95% CI, 18.9-34.2; $P < .001$). According to the KOOS, the incremental improvements were similar for PCL and ACL patients. Time from injury to surgery was longer for the PCL patients compared with ACL patients (median, 21.5 vs 8.0 months; $P < .001$).

Conclusion: Patients undergoing PCL reconstruction can expect the same improvements in KOOS score as patients undergoing ACL reconstruction. However, PCL patients start out with an inferior score on average and consequently end up at a lower score compared with ACL patients for all KOOS subscales.

Keywords: PCL; knee; ACL; register study; single-bundle surgery

*Address correspondence to Christian Owesen, MD, Department of Orthopaedic Surgery, Akershus University Hospital, 1478 Lørenskog, Norway (email: christian.owesen@medisin.uio.no).
[†]Department of Orthopaedic Surgery, Akershus University Hospital, Lørenskog, Norway.
[‡]Diakonhjemmet Hospital, Oslo, Norway.
[§]Department of Orthopaedics, Oslo University Hospital, Oslo, Norway.
[‖]Faculty of Medicine, University of Oslo, Oslo, Norway.
[¶]Oslo Sports Trauma Research Center, Oslo, Norway.
[#]Department of Physical Medicine and Rehabilitation, Oslo University Hospital, Oslo, Norway.
[**]Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, Oslo, Norway.
[††]Norwegian Knee Ligament Registry, Bergen, Norway.

Isolated posterior cruciate ligament (PCL) ruptures are less common knee injuries compared with anterior cruciate ligament (ACL) ruptures. Isolated PCL injuries account for approximately 17% of all knee ligament injuries.[11] In a newly published article examining the epidemiology of all knee injuries among US high school athletes, the prevalence of ACL injuries was 25.4% and that of PCL injuries was 2.4%.[21] Although isolated PCL injuries are not uncommon in contact sports, such as American football, rugby, and soccer, few studies have reported the treatment and follow-up of isolated PCL injuries. Thus, it is difficult to provide evidence-based advice to patients concerning their treatment options. The majority of isolated PCL injuries are benign when it comes to regaining preinjury activity level.[19] However, the injury can be disabling for the affected patient, and it commonly results in a long recovery period. In some cases, the athlete may never compete again at the same level.[18,19] Usually, a nonoperative

approach is first tried; for the majority of patients, this treatment approach results in a return to the preinjury activity level.[16,19] Limited research is available to provide universal guidelines for the nonoperative treatment approach, but active rehabilitation, including a PCL brace, and focusing on regaining range of motion, strength, and stability training (focusing on quadriceps strength in particular) have been described in several studies.[19] In a previous study, 22 of 133 patients with a grade I or II injury (partial ruptures) were unable to return to playing sports at any level after a standard regimen of nonoperative treatment.[19] No similar studies have reported on grade III (total rupture) injuries, although total ruptures take longer to rehabilitate and are considered to be more serious injuries.[16] Some injuries are initially missed and may be recognized months after the actual injury,[16] which could make a nonoperative treatment approach using a PCL brace less likely to succeed because the healing potential for the injured PCL is better in the first weeks after an injury. Patients with poor outcomes after nonoperative treatment are considered for surgical treatment. The definition of a poor outcome varies because there is limited research available to provide guidelines for defining poor outcome. A score of <44 on the Knee injury and Osteoarthritis Outcome Score (KOOS) quality of life (QoL) subscale has previously been suggested to signify treatment failure in terms of evaluating patient outcomes after ACL reconstruction.[2] Because of the limited data available, the surgical indications may differ from country to country. There may also be variations from one hospital to another. Further research in this area is needed. There is a lack of knowledge on the surgical treatment of PCL injuries compared with a control group with nonoperative treatment. The same is true when it comes to comparing results after PCL reconstruction with other ligament reconstructions. Additionally, the existing literature on PCL injuries is dominated by case studies composed of isolated, complete, and combined PCL injuries, making it difficult to apply these findings to isolated PCL injury patients. Consequently, there is a need to further scrutinize isolated PCL injuries.

The aim of this study was to evaluate postoperative results 2 years after primary PCL reconstruction and to compare the results to postoperative results 2 years after primary ACL reconstruction. ACL surgery has been established as a procedure that provides nearly normal restoration of knee function and marked improvement in quality of life assessments.[13,22] Our hypothesis was that 2 years after ligament reconstruction surgery, patients with a PCL injury benefit as much from surgery as patients with an ACL injury, as measured by the KOOS knee function score.

METHODS

Patients were included from the Norwegian Knee Ligament Registry (NKLR). The NKLR was established in 2004. The main objective of the registry was to prospectively register all surgical procedures on cruciate ligaments in Norway and to monitor the outcomes. Every hospital in Norway reports cruciate ligament reconstructions to the registry. Both primary and revision procedures are reported. The report rate
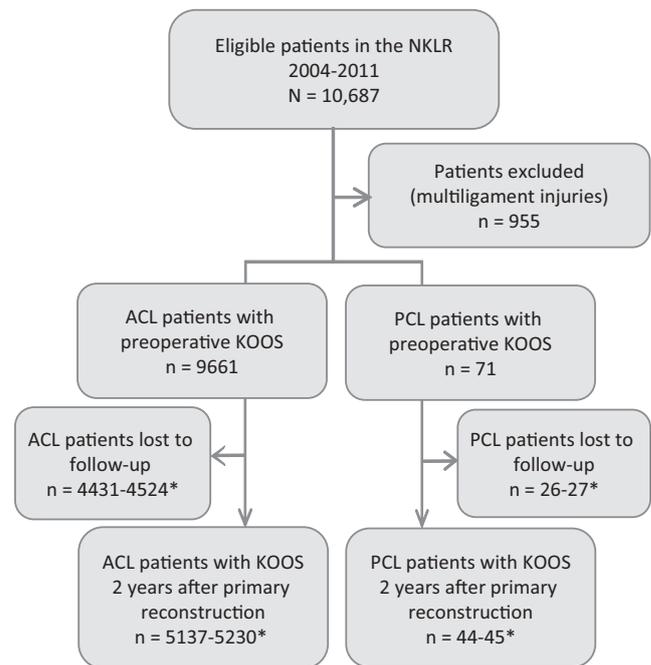

Figure 1. Flowchart showing the inclusion of patients in the current study. ACL, anterior cruciate ligament; NKLR, Norwegian Knee Ligament Registry; PCL, posterior cruciate ligament. *Different numbers indicate the different Knee injury and Osteoarthritis Outcome Scale (KOOS) subgroups.

to the registry is approximately 86%.[25] The patients complete the KOOS report preoperatively and at 2, 5, and 10 years postoperatively. Informed consent is obtained from all patients for the preoperative KOOS score. The surgeon completes a form postoperatively, with information regarding the findings and specifications of the performed procedure. The registry has been described in more detail in previous studies.[4-6,25]

The KOOS questionnaire is a self-administered knee function score that consists of 42 questions divided into 5 different subscales: pain, other symptoms, activities of daily living (ADL), function in sports/recreation, and knee-related QoL. It was developed in the 1990s by Roos et al.[15] The KOOS score includes the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index in its complete and original format, and it is a validated and reliable tool for measuring knee function in patients with osteoarthritis and for several types of knee injuries, including ACL injuries, meniscal injuries, and cartilage injuries.[14] Each subscale ranges from 0 (worst) to 100 (best). A difference of 8 to 10 points in a subscale is usually considered to represent a clinically relevant effect. It is recommended to evaluate each subscale independently when considering outcome measures.[15] In this study, the calculation of each subscale score and the treatment of missing data were performed according to the guidelines of Roos et al.[15]

A total of 10,687 patients with primary ACL and PCL reconstructions were registered in the NKLR between 2004 and 2010. Only patients with an isolated ACL or PCL

TABLE 1
Demographics of Patients Included and Patients Lost to Follow-up[a]

	PCL Injuries		ACL Injuries	
	Lost to Follow-up (n = 26-27)	Postoperative (n = 44-45)	Lost to Follow-up (n = 4431-4524)	Postoperative (n = 5137-5230)
Age at injury, y, mean ± SD	23.7 ± 9.3	23.3 ± 10.3	25.8 ± 9.4	26.7 ± 10.2
Age at surgery, y, mean ± SD	26.0 ± 9.2	27.7 ± 10.8	27.7 ± 9.9	28.7 ± 10.6
Median time from injury to surgery, mo	22.5	20.5	8.0	8.0
Sex, male/female, n	16/10	19/26	2871/1640	2649/2502
	61.5%/38.5%	42.2%/57.8%	63.6%/36.4%	51.3%/48.7%
Meniscal lesions,[b] n (%)	3 (11.5)	5 (11.1)	2217 (49.3)	2539 (49.2)
Cartilage lesions (ICRS grade 1-4),[b] n (%)	6 (23.1)	14 (31.1)	1033 (23.0)	1301 (25.2)

[a]ACL, anterior cruciate ligament; ICRS, International Cartilage Research Society; PCL, posterior cruciate ligament.
[b]Some knees had multiple lesions.

TABLE 2
Results 2 Years After Primary ACL and PCL
Reconstruction, as Measured by KOOS[a]

KOOS Subscale	Mean Score, Preop/2-y Follow-up	Change (95% CI)	P Value
Symptoms			
ACL (n = 5230)	72.7/77.3	5.1 (4.1 to 5.2)	<.001
PCL (n = 45)	63.4/64.3	0.9 (–6.6 to 8.3)	.82
Pain			
ACL (n = 5149)	74.3/84.9	10.5 (10.2 to 11.1)	<.001
PCL (n = 45)	57.5/72.6	15.1 (8.5 to 21.8)	<.001
ADL			
ACL (n = 5150)	83.1/91.2	8.1 (7.7 to 8.6)	<.001
PCL (n = 45)	68.7/81.9	13.2 (6.6 to 19.9)	<.001
Sports			
ACL (n = 5137)	43.1/66.1	23.0 (22.2 to 23.8)	<.001
PCL (n = 44)	25.6/46.3	20.7 (11.8 to 29.4)	<.001
QoL			
ACL (n = 5192)	34.9/66.6	31.7 (31.0 to 32.4)	<.001
PCL (n = 45)	26.4/53.0	26.6 (18.9 to 34.2)	<.001

[a]ACL, anterior cruciate ligament; KOOS, Knee injury and Osteoarthritis Outcome Scale with subgroup symptoms, pain, activities of daily living (ADL), sports/recreation, and knee-related quality of life (QoL); PCL, posterior cruciate ligament; Preop, preoperative.

injury were included to avoid the effects of having more complex knee ligament injuries included in the current trial. Here, we define isolated PCL ruptures as PCL injuries with or without concomitant meniscal or cartilage damage but without any other ligament injury or injuries to the posterolateral corner. We also excluded patients with fractures, patella tendon ruptures, and other serious injuries (nerve and blood vessel injuries), as these are special cases (Figure 1). Patients with concomitant meniscal and cartilage injuries were included because they are commonly associated with both isolated ACL and PCL injuries. A total of 9661 patients with primary isolated ACL ruptures and 71 patients with primary isolated PCL ruptures were initially included (Figure 1). There was a loss of patients to follow-up, with demographic data presented in Table 1. The

median patient age at the time of surgery (±SD) was 26.2 ± 9.9 years for ACL patients and 23.4 ± 9.8 years for PCL patients. KOOS score at 2-year follow-up was 2.1 ± 0.2 years. Autografts were most commonly used with both ACL (99.8%) and PCL (95.8%) ruptures; hamstring and patella tendon grafts were applied: 71.1% hamstring tendons in the ACL reconstructions and 78.9% hamstring tendons in the PCL reconstructions. The distribution of meniscal and cartilage lesions found during surgery in the isolated ACL- and PCL-injured knees registered in the NKLR register have been described in a previous study.[1]

In the present study, all patients from these cohorts who had completed the KOOS scale at 2-year follow-up were included, representing a total of 5192 (56%) patients with isolated ACL ruptures and 45 (65%) patients with isolated PCL ruptures.

Statistical analyses were performed using R software (http://www.R-project.org) and SPSS Statistics for Windows (version 21.0; IBM Corp). Data were compared with the results from a previous study.[1] Mean KOOS subscale scores for the different subgroups were calculated preoperatively for both the ACL and PCL groups. These values were then compared with the corresponding values at the 2-year follow-up, and 95% CIs were calculated based on paired-sample t tests. Then, the changes in the PCL patients were compared with the relative changes in the control group (ACL patients). The chi-square test was used to compare the categorical data. The correlation was calculated using the Pearson correlation coefficient.

RESULTS

The delay to surgery was longer for PCL patients compared with ACL patients (median, 21.5 vs 8.0 months; $P < .001$). None of the improvements observed in the KOOS subscale scores differed significantly between PCL and ACL patients. There were significantly greater numbers of meniscal lesions among ACL patients ($P < .001$) and cartilage lesions (International Cartilage Repair Society [ICRS] score, 1-4) among PCL patients ($P = .02$).
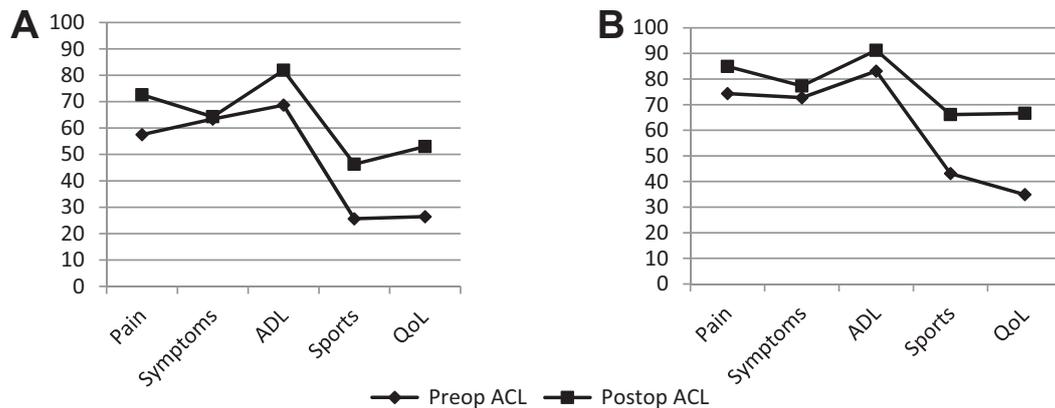
Figure 2. (A) Pre- and postoperative PCL KOOS score. (B) Pre- and postoperative ACL KOOS score. ACL, anterior cruciate ligament; ADL, activities of daily living; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, knee-related quality of life; PCL, posterior cruciate ligament.

At postoperative follow-up, the score increase for PCL patients ranged from 0.9 to 26 for all KOOS subscales. The score increase for PCL patients was significant and clinically relevant for all subgroups, except for the symptoms subscale (Table 2). PCL patients demonstrated greater postoperative improvements in the pain and ADL subgroups than ACL patients (Table 2); however, this finding is not statistically significant. For PCL patients, the greatest change was observed in QoL (26.6 points). There was a significant correlation between the preoperative QoL score and that at follow-up, with a Pearson correlation coefficient of $r = 0.3$ ($P = .04$).

For the ACL group, the scores were significantly increased in all subgroups, although the symptom score only increased by 4.7 and the ADL score increased by 8.1 points; neither of these increases is considered to be clinically relevant (Table 2). During the follow-up period, 428 patients (4.4%) had their ACLs revised, and 1 patient (1.4%) underwent revision surgery after primary PCL reconstruction.

DISCUSSION

The key finding of the present study was that at 2 years, the improvements in the KOOS subjective outcome scores in patients with isolated PCL injuries are equivalent to that in ACL patients. This result is novel because previous studies have not included a comparison group for the observed improvement other than the preoperative scores in the group studied. PCL patients have overall lower KOOS subscale scores both preoperatively and at 2 years. The differences in the KOOS score cannot be explained by sex, time from injury to surgery, or patient age.[1] Further and larger studies are needed to address why PCL patients have lower knee function scores compared with ACL patients.

Previous studies have claimed that there is a higher threshold for the surgical treatment of PCL injuries compared with ACL injuries,[8] which can partly be explained by the incidence of the injuries and perhaps, by the fact that the PCL surgery is more technically demanding than ACL

surgery. Whereas ACL injuries are fairly common and many orthopaedic surgeons have broad experience in treating such injuries, the opposite is true of PCL injuries. Thus, there is a lack of consensus regarding both how to treat the patients and when to perform surgical reconstruction, which also implies that the preoperative score used in many studies as the baseline might vary between different studies. Part of the improvement observed might be related to a focused rehabilitation program and not necessarily the surgical procedure itself. The nonoperative treatment approach and the duration of the rehabilitation program for both ACL and PCL patients should be fairly similar in terms of regaining range of motion, stability, and muscle strength. It has been suggested that, as is evident in this study, instability is the primary issue in the ACL-injured knee and that pain might be the primary issue in knees with PCL injuries[1] (Figure 2). However, to assess the benefits of surgery, a commonly used knee score, such as the KOOS scale, is important. In addition, the use of comparable knee surgery procedures makes it possible to evaluate these issues more objectively compared with baseline scores. Based on our results, it is evident that there is no difference between the observed improvements in patients with isolated PCL injuries and those seen in patients with ACL injuries. It is likely the previously suggested value of 44 points or less on the KOOS QoL measurement can be used as a guideline when choosing surgical treatment. As demonstrated in the current study, there is a significant correlation between the preoperative QoL score and that at follow-up. According to the guidelines for treating ACL injuries provided by the American Academy of Orthopaedic Surgeons, important indications for surgery are the preinjury activity level and the fear of future giving-way episodes. Preoperative screening programs evaluating patients as either copers or noncopers have also been considered to be important for outcomes.[3] These factors may also be important for PCL injuries, but further studies are needed. The time elapsed from injury to surgery might also explain some of the differences in the number of cartilage injuries.[20] Over time, many patients with PCL injuries develop medial and

patellofemoral osteoarthritis.[18] In some cases, this development can be explained by the greater number of injuries to the articular cartilage. Another important explanation is the altered biomechanics of the medial and patellofemoral joint of a PCL-deficient knee.

Whether single-bundle surgery is the ideal technique for treating PCL injuries based on the anatomy is a matter of debate.[24] A recent cadaveric biomechanical study has demonstrated differences in results depending on whether the single- or double-bundle technique was used.[7] Similarly, a recent clinical study has also reported better stability using the double-bundle technique.[9] This finding may alter our surgical approach to treating these patients in the future, and as such, there is potential for even more substantial improvements in functional outcomes than those observed in the current study. Further clinical trials are warranted to determine if this is the case.

One limitation of our study is that we only examined isolated PCL injuries. The results for combined injuries may differ, but this investigation was not within the scope of our current study. Our study was based on data from a registry; thus, there is also the potential for underreporting of associated injuries, which could theoretically affect the results in either direction. Another limitation is that we do not have a matched control group for the study population. The registration rate of 86% could also theoretically affect the results. The registry contains no objective clinical information and no grading of injuries. The operations have been performed by several surgeons using different grafts for reconstruction. This might affect the results in either way. The true baseline KOOS values could be either lower or higher than what is found in the registry. In the majority of cases analyzed in this study, the surgeries used the single-bundle technique with hamstring autograft, which could result in smaller benefits of surgery compared with other techniques. However, these data were included in the registry, and if double-bundle surgery for PCL injuries becomes more commonly used, it can be evaluated by future studies. Another limitation of the study—the use of a nationwide registry that reported the results from 1 specific country—can also be considered a strength. However, other studies have demonstrated that the registry's knee ligament results are comparable with the results in neighboring countries and the United States. Whether the results can be extended to other regions, including Asia, must be investigated further in similar studies from these regions.[5,10,12]

We performed a follow-up of 63% of the KOOS scores at 2 years, which is similar to other registry studies. This represents a lower follow-up than we hoped for and a loss to follow-up of more than one-third of the patients. However, there were no obvious characteristics of the patients who did not provide KOOS measurements at the 2-year follow-up (see Table 1), except that more women participated in the follow-up. This finding was true for both ACL and PCL patients. It is also a consistent finding in survey response rates (based on sex) from other (medical) research fields.[17,23] It is unknown if or how this finding affects the results, but there are no significant differences in the preoperative or postoperative scores between men and women.

CONCLUSION

Patients suffering from isolated PCL injuries benefit as much as ACL patients from surgery, according to incremental increases in KOOS scores at 2 years, despite the fact that PCL-injured patients have an overall lower KOOS score preoperatively and at the 2-year follow-up. Additionally, PCL patients wait longer for primary reconstruction than ACL patients, which might reduce functional improvement after surgical treatment.

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III

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Epidemiology of surgically treated posterior cruciate ligament injuries in Scandinavia

Christian Owesen[1] · Stine Sandven-Thrane[2] · Martin Lind[3] · Magnus Forssblad[4] · Lars-Petter Granan[5] · Asbjørn Årøen[1]

Abstract

Purpose The main purpose of the study was to provide an overview of injury mechanisms, concomitant injuries, and other relevant epidemiological data for patients treated in Scandinavia with posterior cruciate ligament reconstruction (PCLR) following a posterior cruciate ligament (PCL) injury.

Methods A total number of 1287 patients who underwent PCLR from 2004 to 2013 in the Scandinavian counties were included from the national ligament registries. The variables such as age, sex, activity, and graft used for reconstruction were collected. Then, injuries were sorted based on concomitant injuries. Finally, data from the different registries were compared.

Results Average age of the treated patients was 32.7 years. Sex distribution ratio of male to female was 858:429 (66.7 %:33.3 %). Depending on definition, 26–37 % of the injuries treated were isolated PCL injuries. PCL injuries were most commonly encountered in sports with 35.4 % of the total number of PCL injuries in the study population. Soccer was the sport with the highest number of injuries (13.1 %). Cartilage lesions occurred in 26.1 % of PCL injuries and meniscal lesions in 21.0 %. Minimum one other additional ligament was injured in 62.2 %.

Conclusion Isolated PCL injuries are common, although the injury is most commonly associated with other ligament injuries. There is a high prevalence of cartilage injuries and meniscal lesions associated with PCL injuries. Sports are the leading cause of PCL injuries treated operatively. Epidemiological data are a necessary part of the basis for injury prevention in the future. The prevalence of concomitant injuries is also relevant and clinically important for the choice of surgical procedure and for the expected outcomes following surgery.

Level of evidence II.

Introduction

The posterior cruciate ligament (PCL) is the stronger of the two cruciate ligaments in the knee and accounts for about 95 % of the total restrain to posterior translation of the tibia in regard to the femur [1]. In addition, the PCL has secondary stabilizing functions; it restraints rotation when the knee is flexed and remains in varus and valgus position when the knee is extended [2, 3].

The reported incidence of PCL injuries shows a great variation and is reported to be responsible for 1–44 % of all acute knee injuries [4]. This large variation might be due to some authors concentrating on trauma settings and others on the athletic population [5, 6]. There is also a variation in the report rate of isolated PCL injuries. Schulz et al. [6] reported that 47 % of the cases had isolated injuries and 53 % had concomitant injuries, according to the degree of posterior displacement (5–12 mm was classified

✉ Christian Owesen
owesen@getmail.no; christian.owesen@medisin.uio.no

1 Ortopedisk klinikk, Ahus, 1478 Nordbyhagen, Norway

2 Nevrologisk avd, Ahus, 1478 Nordbyhagen, Norway

3 Idrætssektoren, Ortopædkirurgisk Afd, Århus Sygehus, Tage Hansens Gade 2, 8000 Århus, Denmark

4 Capio Artro Clinic, Stockholm Sports Trauma Research Center, Valhallavagen 91, 114 86 Stockholm, Sweden

5 Senter for idrettsskadeforskning, Norges idrettshøgskole, Sognsveien 220, Postboks 4014 Ullevål Stadion, 0806 Oslo, Norway

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as an isolated injury). Fanelli et al. [5, 7] on the other hand reported that the incidence of isolated injuries was 7.5 % and that 92.5 % was concomitant injuries (evaluated by arthroscopy). There is also some discrepancy when it comes to concurrent cartilage and meniscal lesions. Two previous studies describe observed cartilage lesions in about 30 % of the isolated PCL injuries [8, 9]. However, in a recent study, the reported incidence of cartilage injuries ICRS grade 3–4 was 9.9 % [10]. Geissler and Whipple [11] reported that out of 33 patients assumed to have an isolated PCL injury, 12 % also had cartilage defects and 27 % had meniscal tears.

The reported causes of PCL injuries are heterogeneous. Traditionally, the classic PCL injury is a result of a dashboard injury in traffic accidents, and traffic accidents have been considered a major cause of injuries to the PCL. Schulz found that 45 % of the PCL injuries were caused by motor vehicle accidents, and about 40 % were sports related. They also found that motorcycle accidents accounted for 28 % of the total PCL injuries and that soccer injuries accounted for 25 %. In soccer, the goalkeeper was most exposed to this type of injury [6]. Fanelli et al. [7] found that 56 % were trauma patients and 33 % were sports related. The most common pattern of injury is reported to be dashboard injuries and fall on the flexed knee with the foot plantar flexed [6].

It is clear that basic knowledge regarding aetiology of PCL injuries and their concomitant injuries is lacking. This fact makes it difficult to assess the representativeness of the different materials presented in the orthopaedic journals. The present study aims to present an unselected material of this knee ligament injury in order to cover this lack of knowledge in the literature. Since the Scandinavian cruciate ligament registries were established, there is only one published study focusing on the injured PCL [10]. Traditionally, PCL injuries have been treated nonoperatively, but this has over the years changed in favour of surgical reconstruction [12]. Since the Scandinavian registries include a high number of PCL reconstructions (PCLR), it is possible to make an analysis of injury mechanisms and concomitant injuries in those treated surgically.

Materials and methods

The study design is a cross-sectional study on the activities leading to PCL injuries and concomitant injuries using data from the Scandinavian knee ligament registries. Patients were included from The Norwegian Knee Ligament Registry (NKLR), the Swedish Knee Ligament Registry (SKLR), and the Danish ACL Reconstruction Registry (DKRR). The NKLR was established in 2004 followed by the Swedish and Danish registries in 2005. The main objective of the NKLR was to prospectively register all surgical procedures on cruciate ligaments in Norway and to monitor the outcomes. Every hospital doing knee surgery in the Scandinavian countries reports knee ligament reconstructions to the respective registries. Both primary reconstructions and revision procedures are reported. The report rate to the Norwegian registry is approximately 86 % for anterior cruciate ligament (ACL) injuries with similar rates in Sweden and Denmark [13–15]. The registries contain no clinical information or grading of the PCL injuries. Information such as age, sex, activity leading to the injury, and any concomitant injury to the same knee is registered [16, 17]. A validated, self-reported knee outcome score form, The Knee Injury and Osteoarthritis Outcome Score (KOOS), is completed by the patients preoperatively and at follow-up on all patients at 1 or 2, 5, and 10 years post-operatively depending on country [16, 17]. In addition, both the Swedish registry and DKRR include EQ-5D, and DKRR also includes Tegner activity score. In Norway, informed consent is obtained from all patients for the preoperative KOOS, whereas this is not the case in Denmark and Sweden due to different legal requirements [18]. The surgeon completes a form post-operatively, with information regarding the findings and specifications of the performed procedure—including any concomitant injury to any other ligaments, menisci, joint cartilage, major nerve, and blood vessel injury. The cartilage injuries are graded according to the International Cartilage Repair Society (ICRS) grading scale 1–4 [19]. Any procedure to treat these injuries is also registered. The report rates to the respective registries have been fairly consistent in the registration period. When checked against each of the countries national patient registries, the report rates are about 90 %. The registries have been described in more detail in previous studies [15–17, 20].

For each of the registries, we calculated the patients mean age (Table 1), sex distribution (Fig. 1), and the number of the different grafts utilized and the total

Table 1 Age distribution PCLR

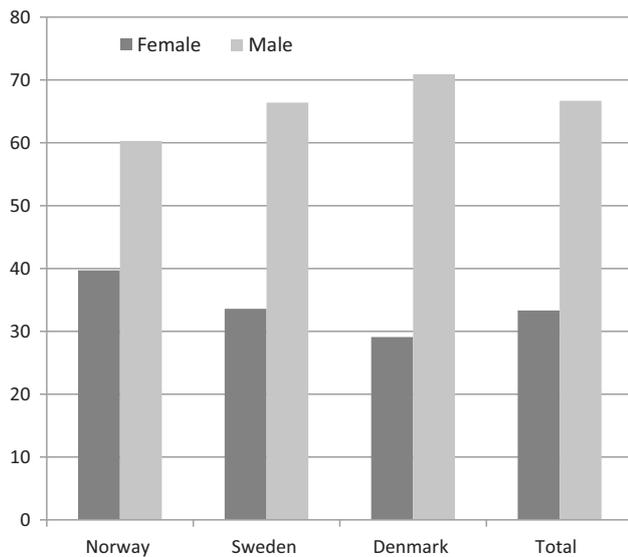| Sex	Norway avg.	Range	Sweden avg.	Range	Denmark avg.	Range	Total avg. age	Range
Female	32.6	14.2–67	30	12–62	32.7	15.6–59.9	31.9	12–67
Male	34.9	15–67	32	8–66	33.0	15.5–59.6	33.2	8–67
Total	34.0	14–67	31	8–66	32.9	15.5–59.9	32.7	8–67

Fig. 1 Sex distribution Scandinavian PCLR

Table 2 Age distribution ACLR

Sex	Norway avg.	Sweden avg.	Denmark avg.	Total avg. age
Female	25.8	27.0	29.6	27.8
Male	27.4	28.0	31.0	29.2
Total	26.7	27.6	30.5	28.7

averages (Table 6). The patients were then sorted into groups (Table 5): isolated PCL injuries; PCL and other ligament injuries; PCL, other ligament injuries, and meniscal injuries; PCL, other ligament injuries, and cartilage injuries; PCL, other ligament injuries, cartilage injuries, and meniscal injuries; PCL and meniscal injuries; PCL and cartilage injuries; and PCL, meniscal injuries, and cartilage injuries. The injuries were sorted by the activities leading to the injuries (Table 3). Activities with quite high prevalence were kept separate, and activities with low prevalence (<1 %) were put together in joint categories. Corresponding data and variables for ACLR from the registries during the same period were used as a comparison to the PCLR data. Further, data regarding activity and concomitant injuries from the different registries were compared in order to look for differences and similarities between the three registries. The groups with the most obvious discrepancies were used to illustrate these differences.

Ethics

Participation in the Norwegian and Swedish registries is voluntary for both surgeons and patients. Patients sign an informed consent, and in Norway, the NKLR is approved by the Norwegian Data Inspectorate. Similar rules and restrictions apply for the SKLR, although informed consent from the patients is not required. In Denmark, reporting to DKRR is mandatory for all clinics, and informed consent from the patients is not required. All data extracted from the registries are anonymized.

Statistical analysis

The Statistical Analysis Product and Service Solutions (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, version 20.0. Armonk, NY: IBM Corp) has been used to perform the descriptive analysis. The Chi-square test was used when comparing prevalence and the categorical data. Prevalence was calculated based on population size for the respective countries in the years 2004–2013, numbers provided by Wikipedia.

Results

The total number of primary PCLR in the Scandinavian registries was 1287 in the years 2004–2013. The registries contain information on about 19,000 patients in Denmark, 17,000 patients in Norway, and 23,000 patients in Sweden during the same period. Among the PCLRs, there were two-thirds men and one-third women. The average age at the time of injury of the patients treated was 32.7 years (Table 1). The most frequent cause of PCL injury is sports with soccer as the largest contributor with. About one-fourth of the injuries was isolated PCL injuries (injury to no other structures injured registered), and in more than one-third of the reported cases, PCL was the only ligament injured (Table 5). The ligament most commonly injured together with the PCL was the ACL. A total of 270 patients had meniscal lesions and 337 had a cartilage injury ICRS grade 1–4. The most common graft used in reconstruction was hamstring autograft (Table 6).

For the ACLR patients, the average age was 28.5 years (Table 2). Male-to-female ratio was 60:40 (Fig. 2). The far most important activity causing the injuries was soccer. All sports in total account for about 80 % of the ACL injuries (Table 4). Compared to the ACLR group (Table 2), the PCLR patients are significantly older ($p < 0.001$). The male-to-female ratios are fairly similar with no significant differences. When it comes to the activity causing the injury, there are some differences. Football (soccer) is the single most common sports leading to both injuries (Tables 3, 4), but it accounts for a significantly higher number of the ACLRs compared to the PCLRs ($p < 0.001$). All sports in total account for a significantly higher percentage of the ACL injuries compared to the PCL injuries ($p < 0.001$). Traffic is a significantly more important cause
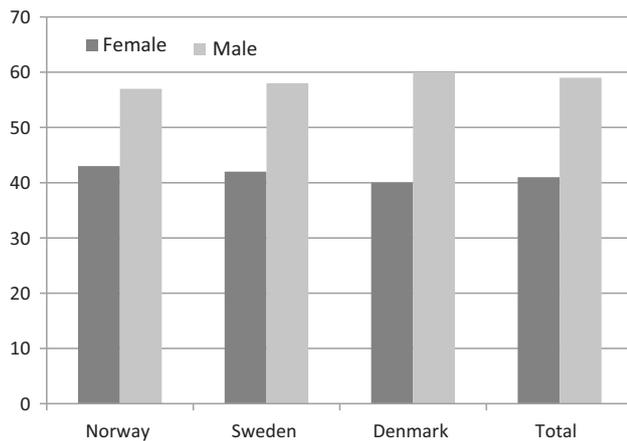
Fig. 2 Sex distribution Scandinavian ACLR

of the PCL injuries ($p < 0.001$). There are also other categories with significant differences between the two types of injury, but the above mentioned are the most obvious.

There was a higher prevalence of PCLRs performed among the total national population from 2004 to 2013 in Denmark 10.6/100.000, 95 % confidence interval CI (8.0, 13.2) and Norway 7.4/100.000, CI (4.6, 10.2) compared to Sweden 3.6/100.000, CI (1.5, 5.7). The differences between the countries are statistically significant ($p < 0.001$). There was also a statistically significant higher prevalence of cartilage lesions in Norway 37.3 %, 95 % CI (32.4, 42.2) and Sweden 37.8 %, CI (32.5, 43.1) compared with Denmark 12.5 %, CI (9.8, 15.2), ($p < 0.001$). Among the PCLRs, there was also a statistically significant higher prevalence of meniscal lesions in Norway 24.2 %, CI (19.9, 28.5) and

Sweden 23.5 %, CI (18.9, 28.1) compared to Denmark 17.4 %, CI (14.3, 20.5), ($p < 0.001$).

Discussion

The main findings of this study were that the number of isolated PCL injuries account for about one-third of the total number of PCL injuries (Table 5). This is new information regarding knee ligament injuries. Isolated PCL injuries are therefore clinically important. Despite this, injuries to the PCL most often appear together with other ligament injuries, where a combination with ACL is the most common. PCL injuries together with meniscal or cartilage lesions, but no other ligament injury, are quite rare, each accounting for 3.0 and 6.5 %, respectively, and 1.9 % with combination of both meniscal and cartilage lesions. Meniscal and cartilage injuries are usually seen when there are other ligament injuries accompanying the PCL injury. They both appear in similar frequencies (Table 5). This can be explained by the injury mechanism involving forces with a higher amount of energy causing the injury. An isolated PCL injury often occurs as a result of a dashboard injury, fall on flexed knee, or hyperextension of the knee as is shown by anatomical and biomechanical studies focusing on the stabilizing function of the PCL [12, 21–23]. PCL injuries in combination with another ligament injury are more likely when the mechanism of injury contains a rotational component and/or valgus/varus stress. Meniscal and cartilage lesions are also more likely to occur when there are rotational forces and/or varus and valgus stress involved [24–26]. One could speculate that there is some degree of relation between the injury mechanism and the concomitant injuries.

Table 3 PCL injuries by activity

Activity	Norway	Sweden	Denmark	Total
Football (soccer)	38 (10.1 %)	51 (15.6 %)	79 (13.1 %)	168 (13.1 %)
Handball	30 (8.0 %)	14 (4.3 %)	36 (6.2 %)	80 (6.2 %)
Snowboard	6 (1.6 %)	2 (0.6 %)	1 (0.2 %)	9 (0.7 %)
Alpine skiing (incl. twin tip)	33 (8.8 %)	33 (10.1 %)	35 (6.2 %)	101 (7.8 %)
Other ski activity	58 (15.5 %)	2 (0.6 %)	1 (0.2 %)	61 (4.7 %)
Martial arts	4 (1.1 %)	7 (2.1 %)	2 (0.3 %)	13 (1.0 %)
Team sports (ice hockey, bandy, etc.) inline skating volleyball, basket,	6 (1.6 %)	15 (4.3 %)	4 (0.7 %)	25 (1.9 %)
Motorsport and car sport including traffic	81 (21.6)	102 (31.2 %)	199 (34.0 %)	382 (29.7 %)
Other physical activity (other sports, dancing, etc.)	53 (14.1 %)	41 (12.5 %)	74 (12.6 %)	168 (13.1 %)
Work related	22 (5.9 %)	19 (5.8 %)	40 (6.8 %)	81 (6.3 %)
Fall, jumping, play including trampoline and skateboard	21 (5.6 %)	3 (0.9 %)	0 (0 %)	24 (1.9 %)
Outdoor recreation	7 (1.9 %)	10 (3.1 %)	0 (0 %)	17 (1.3 %)
Other	6 (1.6 %)	27 (8.3 %)	75 (12.8 %)	108 (8.4 %)
Missing/unknown	10 (2.7 %)	1 (0.3 %)	39 (6.7 %)	50 (3.9 %)
Total	375 (100 %)	327 (100 %)	585 (100 %)	1287 (100 %)

Numbers and percentages for each country and total

Table 4 ACL injuries by activity

Activity	Norway	Sweden[a]	Denmark	Total
Football (soccer)	7043 (40.1 %)	6470 (42.0 %)	7928 (40.4 %)	21,441 (41.1 %)
Handball	2504 (14.3 %)	760 (4.7 %)	3186 (16.3 %)	6450 (12.4 %)
Snowboard	395 (2.3 %)	156 (0.6 %)	68 (0.4 %)	619 (1.2 %)
Alpine skiing (incl. twin tip)	2194 (12.5 %)	1850 (14.4 %)	2406 (12.3 %)	6450 (12.4 %)
Other ski activity	443 (2.5 %)	13 (0.1 %)	28 (0.1 %)	484 (0.9 %)
Martial arts	330 (1.9 %)	356 (2.7 %)	173 (0.9 %)	859 (1.6 %)
Team sports (ice hockey, bandy, etc.) inline skating volleyball, basket,	494 (2.8 %)	2126 (13.4 %)	256 (1.3 %)	2876 (5.5 %)
Motorsport and car sport including traffic	405 (2.3)	574 (3.6 %)	615 (3.1 %)	1594 (3.1 %)
Other physical activity (other sports, dancing, etc.)	993 (5.7 %)	993 (7.8 %)	1973 (10.1 %)	3959 (7.6 %)
Work related	436 (2.5 %)	267 (1.8 %)	550 (2.8 %)	1253 (2.4 %)
Fall, jumping, play including trampoline and skateboard	753 (4.3 %)	115 (1.2 %)	1619 (8.3 %)	2487 (4.8 %)
Outdoor recreation	0 (0.0 %)	185 (1.4 %)	0 (0.0 %)	185 (0.4 %)
Other	1150 (6.6 %)	1106 (6.3 %)	0 (0.0 %)	2256 (4.3 %)
Missing/unknown	409 (2.3 %)	0 (0.0 %)	804 (4.1 %)	1213 (2.3 %)
Total	17,549 (100 %)	14,971 (100 %)	19,606 (100 %)	52,126 (100 %)

Numbers and percentages for each country and total

[a] 2005, 2008, 2009, 2012, and 2013. Data from 2006, 2007, 2010, and 2011 are not available

Table 5 Combinations of injuries

Injured structures	Norway	Sweden	Denmark	Total
PCL	69 (18.4 %)	82 (25.1 %)	189 (32.3 %)	340 (26.4 %)
PCL + other ligament	121 (32.3 %)	86 (26.3 %)	246 (42.1 %)	453 (35.2)
PCL + other ligament + cartilage + meniscus	39 (10.4 %)	31 (9.5 %)	18 (3.1 %)	88 (6.8 %)
PCL + meniscus	7 (1.9 %)	9 (2.6 %)	22 (3.8 %)	38 (3.0 %)
PCL + cartilage	26 (6.9 %)	42 (12.8 %)	16 (2.7 %)	84 (6.5 %)
PCL + meniscus +cartilage	7 (1.9 %)	11 (3.4 %)	7 (1.2 %)	25 (1.9 %)
PCL +other ligament + cartilage	68 (18.1 %)	40 (12.2 %)	32 (5.5 %)	140 (10.9 %)
PCL + other ligament + meniscus	38 (10.1 %)	26 (8.0 %)	55 (9.4 %)	119 (9.2 %)
Total	375 (100 %)	327 (100 %)	585 (100 %)	1287 (100 %)
Total PCL + min 1 other ligament	266 (70.1 %)	183 (60.0 %)	351 (60.0 %)	800 (62.2 %)
Tot. PCL + meniscus	91 (24.2 %)	77 (23.5 %)	102 (17.4 %)	270 (21.0 %)
Tot. PCL + cartilage	140 (37.3 %)	124 (37.9 %)	73 (12.5 %)	337 (26.1 %)
Tot. PCL without other ligament	108 (28.8 %)	144 (44.0 %)	234 (40.0 %)	486 (37.8 %)

Numbers and percentages for each county and total

The distribution of activity shows that almost one-third of the PCL injuries was related to vehicle accidents or motorsports accidents. Football (soccer) and skiing activities were the most important sports activities leading to a PCL injury. Other physical activity (like dancing and some team activities) was also an important category (Table 3). This is in some contrast to classical teaching that clearly states that PCL injuries are almost exclusively the result of traffic accidents. Importantly, the numbers are even more in favour of sports if motorsports are taken away from the traffic category. One can argue that motorsports is not traffic since normal traffic rules do not apply, and it is performed under different circumstances than usual traffic.

This finding is in some contrast to the assumption that PCL injuries result from traffic accidents [7], but corresponds to findings in other studies [4, 6].

There are some differences in the activities leading to the injuries between the respective countries. When it comes to injuries in motorsports and traffic, this is more commonly seen in Sweden and Denmark than in Norway. The difference between Norway and Sweden could theoretically be explained by the difference in licenced competitors of the sports with close to 23.000 members in Norway (Norsk bilsportsforbund) and about 120.000 in Sweden (Svensk bilsport), but in Denmark there are only about 8.000 licenced competitors (Danks bilsport). However, there is another

Table 6 Graft choices

Graft	Norway	Sweden	Denmark	Total
Hamstring	257 (68.5 %)	157 (48.0 %)	237 (40.5 %)	651 (50.6 %)
Allograft	42 (11.2 %)	49 (15.0 %)	197 (33.7 %)	288 (22.4 %)
Patellar tendon	25 (6.7 %)	5 (1.5 %)	9 (1.5 %)	39 (3.0 %)
Direct suture	7 (1.9 %)	22 (6.7 %)	1 (0.2 %)	30 (2.3 %)
Quadriceps	30 (8.0 %)	75 (27.8 %)	141 (24.1 %)	246 (19.1 %)
Unknown	14 (3.7 %)	19 (5.8 %)	0 (0 %)	33 (2.6 %)
Total	375 (100 %)	327 (100 %)	585 (100 %)	1287 (100 %)

Numbers and percentages for each country and total

possible explanation. There was a higher average number per year of seriously injured people in traffic accidents registered in Sweden and Denmark compared to Norway in the years 2004–2012. The numbers for injuries classified as serious were 2689 in Denmark, 1122 in Sweden (numbers available only 2007–2012 for Sweden), and 825 in Norway. These numbers include all injuries classified as serious and not only knee injuries. However, the numbers provide information on how many people are injured in traffic and might say something about the probability of a traffic-related PCL injury. As one might expect, skiing activities (including snowboard) are more common in Sweden and Norway compared to Denmark, as there is only one small ski centre in the whole of Denmark where there are several in both Sweden and Norway.

The graft choices in the registries reflect some difference in practice between the Scandinavian countries (Table 6) and can perhaps be explained by the accessibility of allografts and traditions for using different types of grafts. Denmark is geographically a much smaller country than Sweden and Norway. A higher number of PCL reconstructions are performed at a few referral hospitals, whereas in Norway and Sweden some hospitals perform as few as one or two PCLRs per year. With a higher number of reconstructions, it is easier to obtain allografts and have good procedures performing reconstructions with these grafts. There is a lower prevalence of PCLRs in Sweden compared to the neighbouring countries. One could speculate that this is due to a lower report rate, but this is supposedly not the case as the report rate has been confirmed to be about 90 % for ACLR [13]. As the SKLR was mainly planned as an ACL registry, it could be that there is a lower report rate for PCLR, although this is not known and needs to be further investigated. This leaves two possibilities: that there in fact are fewer occurring PCL injuries in Sweden, or that a lower number of these are treated operatively. Why this remains unclear. There are a lower number of meniscal and cartilage injuries among the Danish PCLR patients. This might be partly due to a higher prevalence of PCL injuries

without any other ligament injury in their population, but exactly why this still remains unclear.

The difference in age for the ACL and PCL patients is similar to what has been found in a previous study [10]. The reason for this difference remains unknown but can possibly partly be explained by a higher number of sports injuries in the ACL group and a higher number of traffic injuries responsible for the PCL injuries. The reason for traffic causing relatively more PCL injuries than ACL injuries is probably related to the injury mechanism with a direct blow against the tibia. The energy involved in traffic accidents is also often higher than in sports injuries. This is relevant information when we know that more energy is needed to tear the PCL than the ACL.

Strengths of this study are that the registries contain information on activity and concomitant injuries. There are a limited number of studies on injury mechanisms and concomitant injuries. Most of the studies in the literature either have small numbers of patients or have focused on trauma patients. Therefore, it is likely that neither of the published studies reflects the true PCL injured population. In the Scandinavian registries, all types of injuries are included from a large geographical area. This provides a more representative estimate than those previously published when it comes to surgically treated PCL injuries. Simultaneously, there are known limitations when using registry data. Nonoperative treatment is an alternative for both ACL and PCL injuries [4, 27]. Information on patients treated nonoperatively is not included in the registries. Objective clinical information is sparse. The registries are not complete, and we do not know for sure how the missing data could affect the results of this study. There could also be underreporting of concomitant injuries by the surgeons as some injuries are easily missed on MRI or by the individual surgeon. This specifically applies to injuries to the posterolateral corner. Only a minority of the total number of patients have undergone stress radiographs, as this is so far only recorded in the DKRR. Another limitation is that this study reflects the Scandinavian population. It is not clear whether findings in

other countries will be comparative as there are differences even between the Scandinavian countries.

Sports are the leading cause of PCL injuries treated operatively in the study population. Epidemiological data are a necessary part of the basis for injury prevention in the future. Increased focus on PCL injuries in sports may lead to interventions aiming to reduce the frequencies of the injuries. The prevalence of concomitant injuries is also relevant and clinically important for the expected outcomes following surgery. It is also important when considering where to treat these patients, as some of the concomitant injuries often require what is usually considered technically demanding surgery. PCL reconstruction should probably be performed in regional hospitals with experienced surgeons used to this type of injuries.

Conclusion

Patients undergoing PCLR in the Scandinavian countries often have other related injuries to the same knee, although isolated PCL injuries are common. The PCL is most commonly injured in sports. The registries in the different countries show some differences in the prevalence of PCLRs and related injuries. The activity leading to the injuries is fairly similar in the different countries with some expected differences, skiing activities are more common causes in Norway and Sweden than Denmark, and traffic including motorsports is more common in Sweden and Denmark compared to Norway. Sports is a more frequent cause of PCL injuries than frequently presented in the literature, and this clinically important information has to be taken into account when assessing the representativeness of research on PCL injuries or other knee injuries involving a PCL injury.

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