"Man kan bare se riktig med hjertet,
det vesentligste er usynlig for øyet"
Ordspråk

Summery

The aim of this thesis was to increase the knowledge about anterior cruciate ligament injuries in team handball through two epidemiological studies ("how many, when, who and how"), one follow-up study ("what is the long term outcome") and a prevention study ("what can be done").

In the first study the total number of cruciate ligament injuries was registered in the three upper divisions in the 1989-91 seasons for men and women. A total of 93 injuries were found, 87 ACL injuries and six PCL injuries. The injury prevalence was higher among women (1.8%) than men (1.0%) and the risk of getting a cruciate ligament injury was highest in highest division (4.5%). Most injuries occurred during matches, where the injury incidence was 0.97 cruciate ligament injuries per 1000 playing hours. Only 5% of the injuries occurred during contact between the players. A high friction between the foot and the floor might have importance.

In the second study the purpose was to examine gender differences in the incidence of ACL injuries among elite level players and look for possible injury mechanisms and risk factors. A total number of 28 ACL injuries was found during the three seasons, 23 among women (incidence: 0.31/1000 playing hours) and five among men (incidence: 0.06/1000 playing hours), the risk ratio was 5.0. Most of the injuries (24) occurred during matches (risk ratio 29.9 compared to training). Most of the injuries were non-contact injuries. There seemed to be an increased risk of getting an ACL injury during the week prior to and after the start of the menstrual period.

A follow-up study of the ACL injured players from the 1989-91 registration was performed to evaluate the consequences of an ACL injury 8 (6-11) years after injury. The players went through clinical examination, knee laxity testing, IKDC evaluation, Lysholm score, strength tests and functional tests, and finally a radiological examination of 50 of the players. Fifty-seven of the players were treated operatively and 22 conservatively. Almost 60% of the players in the operatively treated group returned to team handball at pre-injury level compared with 82% in the conservatively treated group. Of the operatively treated players who continued playing handball, 22% re-ruptured their ACL, while 9% ruptured their opposite ACL. The overall Lysholm score was 85 of a maximum of 100 and there was no difference between the treatment groups. Nearly half of the players were classified as abnormal/severely abnormal (C and D) in the IKDC evaluation, the rest of the players was classified as normal or nearly normal (A and B). Almost half of the players in both groups had developed radiological osteoarthrosis. There was no correlation between radiological findings and pain scores. These results could indicate that a more restrictive attitude concerning the return to high level pivoting sports may be warranted.

An ACL prevention study was performed among female players in the three upper divisions during the 1998-2001 seasons (98-99: Control season, 99-00: First intervention season, 00-01: Second intervention season). All players were asked to perform a neuromuscular training program with increasing difficulty to increase knee awareness and control. There were three sets of exercises, one on the floor, one on a balance mat and finally one on a wobble board. The program lasted for about 15 minutes and the program was done three times a week in a 5-7 week period and then once a week during the season. A physical therapist was assigned to the teams during the second intervention period. The total number of ACL injuries was reduced from 29 in the control season to 23 in the first intervention season and 17 in the second intervention season. In the elite divisions the risk of ACL injury was reduced among the players who performed the program as intended. The study indicates that it is possible to reduce the number of ACL injuries with a special neuromuscular training program.

Key Words: Etiology, cruciate ligament injuries, European team handball, ACL injury, menstrual status, follow-up study, knee function, graft rupture, return to sport, activity level, prevention, neuromuscular training.

Anterior Cruciate Ligament Injuries in Team Handball

— from Injury to Prevention

Dissertation by
Grethe Myklebust

Oslo Sports Trauma Research Center,
Norwegian University of Sport and Physical Education
Oslo, Norway

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Summery

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List of papers

This dissertation is based on the following papers, which are referred to in the text by their Roman numerals:

I. Myklebust G, Maehlum S, Engebretsen L, Strand T, Solheim E. Registration of Cruciate Ligament Injuries in Norwegian Top Level Team Handball. A prospective study covering two seasons. Scand J Med Sci Sports 7: 289-292, 1997

II. Myklebust G, Mæhlum S, Holm I, Bahr R. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. Scand J Med Sci Sports 8: 149-153, 1998

III. Myklebust G, Holm I, Mæhlum S, Engebretsen L, Bahr R. Clinical, functional and radiological outcome 6-11 years after ACL injuries in team handball players – a follow-up study. Am J Sports Med (In press)

IV. Myklebust G, Engebretsen L, Brækken IH, Skjølberg A, Olsen OE, Bahr R. Prevention of ACL injuries in female team handball players— a prospective intervention study over three seasons. Clin J Sport Med 13: 71-78, 2003

Abbreviations

ACL	Anterior cruciate ligament
BPTB	Bone-patellar tendon-bone
IKDC form	International Knee Documentation Committee form, an outcome measurement used after ACL injury.
KT-1000 knee arthrometer	An instrument used to measure the anterior displacement of the tibia relative to the femur (knee joint laxity)
NHF	Norwegian Handball Federation
Femoral Notch	Space between the femoral condyles
OA	Osteoarthritis
OC	Oral contraceptives
PCL	Posterior cruciate ligament
PT	Physical therapist
ROM	Range of motion

Introduction

ACL injuries in team handball

Team handball is one of the most popular sports in Norway. The Norwegian Handball Federation is the third largest sports federation with 96.000 members. About 2/3 of the members are females and 2/3 are under the age of 17.

This study was carried out in order to increase our understanding of anterior cruciate ligament injuries in team handball. This was investigated through two epidemiological studies ("how many, when, who and how"), one follow-up study ("what is the long term outcome") and finally, a prevention study ("what can be done").

It is hoped that the findings of this thesis will contribute towards a better understanding of these issues, especially among female team handball players but perhaps also with relevance for other team sports.

The knee joint

The knee joint is the most complicated joint in the body. It consists of several interacting structures involved in the three-dimensional movements of the joint. High loads are transferred through the knee joint as a result of body weight, muscle forces and of long lever arms.

The main movement between the femur and tibia is flexion-extension, but rotation and varus-valgus movements also take place between the bones.

The stability of the knee joint depends on a fine balance between the ligaments, the menisci and the muscles. The anterior cruciate ligament (ACL) is the most important stabilizer in the knee joint (*Figure 1*).

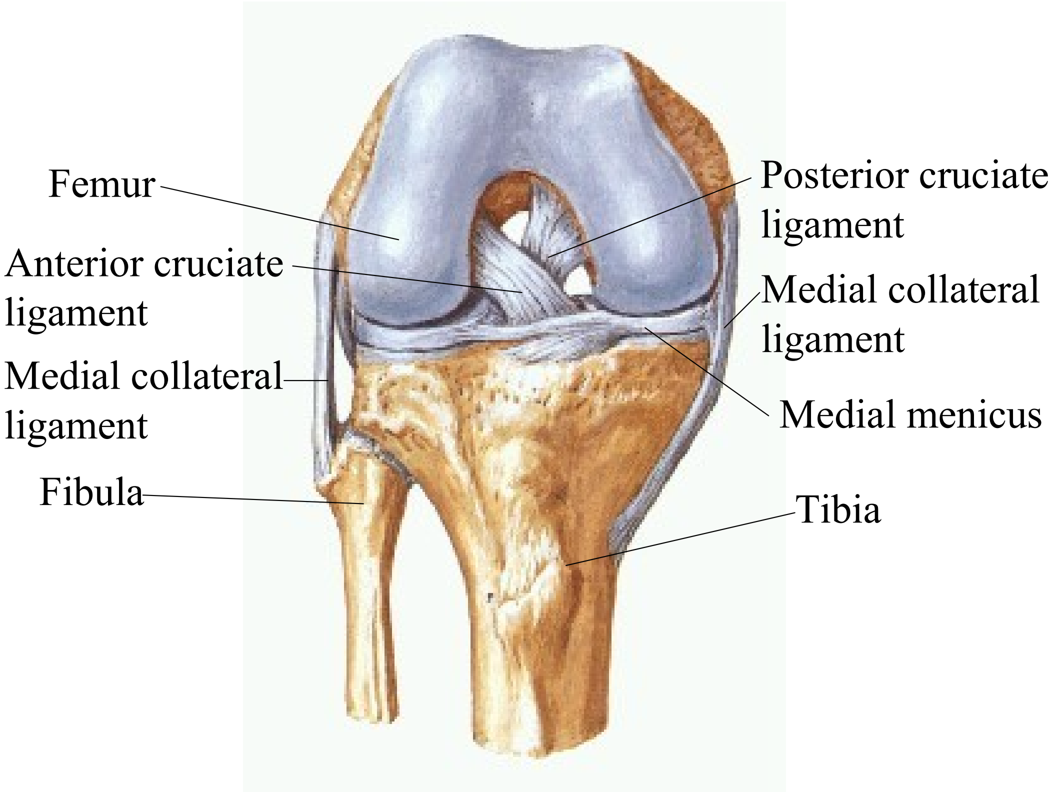

Figure 1. The structure of the knee (the right knee in a frontal view). The patella and the joint capsule is removed. The figure has been modified from Netter (1995).

Function of the ACL

The ACL is a band of regularly oriented dense connective tissue that connects the femur and tibia. The ligament is attached to the posterior aspect of the medial surface of the lateral femoral condyle. On the tibia the ligament is attached to a fossa in front of and lateral to the anterior tibial spine. The ACL passes anteriorly, medially and distally across the joint from femur to tibia. It has a slight spiral form caused by its bony attachments (Odensten and Gillquist 1985). The bony attachments are also responsible for the relative tension throughout the range of motion (Girgis et al. 1975). The ACL consists of two parts, the anteromedial (tight in flexion) and the posterolateral (tight in extension). The average thickness of the ACL is 11 mm, and the average length is reported to range from 31 mm (Girgis et al. 1975) to 38 mm (Odensten and Gillquist 1985). The ACL receives nerve fibres from branches of the tibial nerve. Nerve fibres and sensory organs are located in the ligament (Kennedy et al. 1982; Zimny 1988; Halata and Haus 1989). The finding of mechanoreceptors in the ligament has confirmed that the ACL has a sensory role (Schutte et al. 1987; Schultz et al. 1984).

Biomechanical function

The ACL is the primary restraint against anterior translation of the tibia relative to the femur. It provides 85% of the restraint to anterior translation at 30 degrees of knee flexion (Butler et al. 1989). The ACL also resists hyperextension of the knee, and prevents anterolateral rotatory instability (Girgis et al. 1975). At 0 to 40 degrees of flexion the ACL also act as a valgus-varus stabilizer.

The strength of the ACL is found in young cadaver studies to be about 1750 N, but this depends of the direction of the load applied (Woo et al. 1991). Due to methodological problems nobody has measured the tension directly in in-vivo studies. Various studies however, have shown that there is an increase in ligament strain from 30 degrees of flexion to full extension (Henning et al. 1985; Beynnon et al. 1992; Beynnon et al. 1995; Beynnon et al. 1997). The estimated load of the ACL during daily activities varies between different studies. Morrison (Morrison 1970) estimated a peak load in walking of 169 N, 67 N when ascending a ramp, and about 500 N in descending a ramp. Chen and Black (Chen and Black 1980) estimated the load during jogging to 630 N in 1980. Downhill running seems to create the greatest strain on the ACL (Henning et al. 1985).

Sensory function

As early as 1944 Abbott published a dissertation of knee ligament injuries where he concluded that the knee had rich sensory innervations. Strong impulses initiated when the ligament was overstretched resulted in contraction of muscle groups, thereby protecting the knee, and preventing further injury and subluxation of the knee. Kennedy et al (Kennedy et al. 1982) hypothesized that a knee injury leads to ligamentous instability that results in a failure of mechanoreceptor feedback and loss of reflex muscular contractions. He suggested that this contributed to repetitive injuries and clinical decline.

Most studies have shown a reduced proprioception in the ACL injured knee compared to the normal knee or a control group (MacDonald et al. 1996; Borsa et al. 1997; Barrett 1991; Fischer-Rasmussen and Jensen 2000). The studies on reconstructed knees are less clear. Some find reduced proprioception after a reconstruction (Lephart et al. 1992), others find no difference (Risberg et al. 1999a) and some find a reduced proprioception after surgery but improving over time (Fremerey et al. 2000). This could be explained by the time spent to regenerate the mechanoreceptors in the reconstructed ligament (Risberg 1999).

The muscle activity in the lower extremity protects against injuries in two ways, first by reducing the load on the knee ligaments (Goldfuss et al. 1973) and secondly with a shock absorbing effect. Most studies emphasize the importance of a fast activation of the hamstrings muscles to achieve maximal power in the muscle group as quickly as possible. ACL injured patients who function well recruit the hamstrings muscles faster than patients with an ACL injury and an unstable knee (Beard et al. 1993).

When the strain in the ACL increases, the mechanoreceptors send sensory signals to the spinal cord and the hamstrings muscles fire to protect the ACL, but new studies have shown that the firing of the hamstrings muscles may occur too late to protect against injury (Huston and Wojtys 1996; Simonsen et al. 2000). Hall et al (Hall et al. 1995) found reduced proprioception in people with increased knee laxity and intact ACLs. However, there is so far no evidence that people who are generally lax injure their ACL more often than people with normal laxity (Decoster et al. 1997).

The finding of mechanoreceptors in the ACL has given us a better understanding of the problems many ACL injured people have with their knee function. Patients with ruptured ACLs, whether treated conservatively or with reconstructive surgery, can have significant functional problems with episodes of giving way despite having developed excellent muscle strength in their lower extremities. One reason may be a loss of neuromuscular control after their ACL injury. This experience has had a great impact on the treatment of ACL injuries, and the focus has shifted from strength-based rehabilitation programs to combined programs where both strength and neuromuscular training are used. The neuromuscular training consists of exercises that challenge neuromuscular control, for example balance training on one leg, jump-training and/or perturbation training (introducing an unexpected event that changes the movement or the movement goal).

This is an area in progress, there are still many unanswered questions and the rehabilitation programs will probably change in the future with new knowledge.

Injury incidence

Studies have shown that of injuries recorded at Norwegian hospitals and accident departments, 17% are sports injuries. Of these injuries 33% are caused by football, 20% by skiing and 12% by team handball (Lereim 1997). The severity and the consequences of sport injuries vary. A knee injury is one of the injury types that results in the most serious consequences with respect to absence from sport and work, medical disability and insurance claims. ACL injuries are expensive both for the patient and society. Each ACL injury is calculated to cost between 500.000 and 1.000.000 NOK; in surgical expenses, sick leave, rehabilitation and possibly disability compensation (Engebretsen 2000). The number of operations has increased significantly, from 1000 in 1990 to 2000 in 2000 in Norway (Engebretsen 2000).

The only previous study looking at injury incidence in team handball was a retrospective study published in 1990 (Strand et al. 1990). They interviewed ACL injured players (ten years back in time) from hospital records at two hospitals in Norway (n=144). They found that the incidence of ACL injuries was highest among women playing at the top level with 0.82 ACL injuries per 1.000 playing hours compared to male players with 0.31 injuries per 1000 playing hours.

The gender difference found in the study by Strand et al (Strand et al. 1990) has also been seen in other ball sports like basketball, soccer and volleyball (Hutchinson and Ireland 1995; Arendt and Dick 1995; Ferretti et al. 1992). The rate of ACL injury among women was 2.4 times higher in soccer and 3.0 times higher in basketball compared to men (Arendt and Dick 1995).

In alpine skiing the number of injuries in general have declined over the last two decades, but the number of knee injuries, in particular ACL injuries have increased (Hame et al 2002). Twenty-five to 30% of all ski related knee injuries involve the ACL (Speer et al 1995). The gender difference is not as distinctive in alpine skiing. Viola et al (1999) found a similar incidence rate among male and female skiers in a retrospective review of ACL injuries among professional alpine skiers. However, in a study of competitive alpine ski racers Stevenson (1998) found that the female racers were 2.3 times more likely to sustain an ACL injury than male racers.

The study by Strand et al (Strand et al. 1990) was important since it focused on what appears to be an increasing problem in the sport in general, and team handball in particular, at least based on the number of operations being performed. However, because it was retrospective and covered only a small region of Norway, we thought that there was a need for prospective studies to assess the ACL incidence in team handball and examine the distribution of injuries related to gender. This was the focus of Paper I & II.

Risk factors

When trying to understand the etiology of the ACL injury it is necessary to identify risk factors. It is common to divide risk factors in two main categories: internal and external risk factors (van Mechelen et al. 1992; Arendt and Dick 1995).

When describing the relationship of factors to injury I will use Meeuwisse‘s (Meeuwisse 1994) dynamic multifactorial model of sports injury etiology (*Figure 2*).

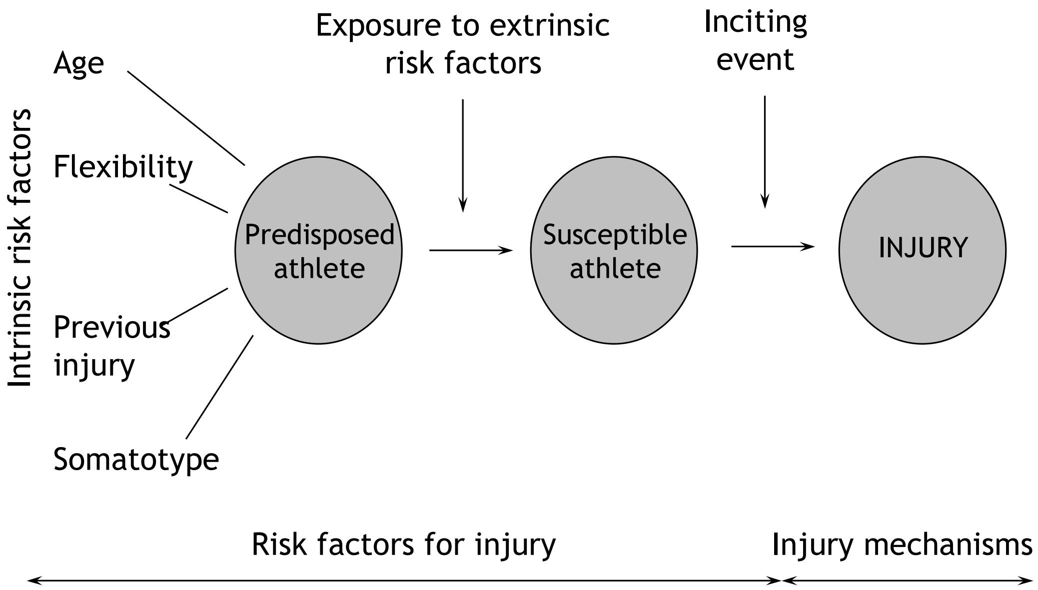

Figure 2: A dynamic, multifactorial model of sports injury etiology. Reprinted with permission from Clinical Journal of Sports Medicine, Lippencott, Williams and Wilkins. (Meeuwisse 1994).

Meeuwisse classifies the intrinsic factors as predisposing factors that are necessary, but seldom sufficient, to produce injury. Intrinsic factors are athlete-related factors, such as gender, age, flexibility, somatotype and previous injury. In his theoretical model extrinsic risk factors (such as playing conditions, weather or equipment), act on the predisposed athlete from without and are classified as enabling factors in that they facilitate the manifestation of injury. The presence of both of these factors are not sufficient to produce injury, it is the sum of these risk factors and the interaction between them that “prepare” the athlete for an injury to occur at a given place, in a given sports situation (Bahr et al. 2002). Meeuwisse describes an inciting event to be the final link in the chain of causation to sports injury and states that such an inciting event is usually directly associated with the onset of injury. Such events are regarded as necessary causes. This inciting event is often described as the injury mechanism. Studies on the etiology of sports injuries tend to focus on the injury mechanism and tend to neglect factors more distant from the injury event (i.e. the intrinsic and extrinsic risk factors). This can cause an overemphasis of such events in both the etiology and prevention of sports injuries (Bahr et al. 2002).

ACL injuries are multifactorial in their etiology (Hutchinson and Ireland 1995; Arendt and Dick 1995; Hewett 2000; Griffin et al. 2000) and it is important to examine which combination of factors that is most essential. For instance, describing an ACL injury as a non-contact or contact injury does provide meaningful information, but leaves us far from having a complete understanding of the injury mechanism (Bahr et al. 2002).

Intrinsic factors: Suggested intrinsic factors include alignment of the lower extremity, femoral notch size and shape, ligament size, coordination and neuromuscular control. In addition, it has been suggested that there may be sex differences in ligamentous laxity, possibly related to cyclic hormonal effects (Hutchinson and Ireland 1995; Hewett 2000), but the results of studies dealing with this issue are inconsistent. Wojtys et al (Wojtys et al. 1998) observed an increased injury risk in the ovulatory phase of the menstrual cycle, while Karageanes et al (Karageanes et al. 2000) did not find any significant change in ACL laxity during the menstrual cycle in a study of 26 young females (age: 14-18).

The size of the femoral intercondylar notch has been extensively debated in the literature. The theory is that notch stenosis results in impingement and tears the ACL (Arendt 2001). There seems to be a consensus implicating that the notch size has a role in relation to ACL injury, but the size of the ACL inside the notch may be more important than the variability of the notch dimensions. The debate continues whether a small notch houses a small ACL and/or if the ACL is at risk because it is smaller and then weaker (Arendt 2001).

Generalized joint laxity or knee hyper-mobility have been suggested as risk factors. The theory is that by the time a lax person senses the knee position, it is too late and the injury will occur (Nichlas 1970, Mortez et al 1982). However, recently Decoster et al (1997) did not find any significant difference in overall injury patterns between hyper-mobile athletes compared to athletes with normal laxity.

Recently the "tibial slope" has been discussed as a possible anatomic risk factor. The theory indicates that the greater the posterior slope, the easier it is for the femur to slide down the slope when the tibia is subjected to a quadriceps force (Arendt 2001). A person with a greater tibial slope could be more susceptible to an ACL injury. This theory has been supported by DeJour and Bonnin (Dejour and Bonnin 1994), they found that for every 10° increase in posterior tibia slope, there is a 6 mm increase in anterior tibial translation. However, these results have not been confirmed by other studies. At this point the theory needs further investigation (Arendt 2001).

Extrinsic factors: Potential extrinsic factors include shoe, playing surface and the shoe/friction interaction. One hypothesis is that high friction between the shoe and floor increases the injury risk. This was hypothesized as early as in 1990 in the study by Strand et al (Strand et al. 1990). They found an increased risk of ACL injuries on synthetic surfaces compared to parquet, with 0.34 ACL injuries per 1000 playing hours on synthetic floors compared to 0.06 ACL injuries per 1000 playing hours on parquet. As part of our research program we have studied the incidence of sustaining an ACL injury related to floor type (Olsen et al. 2003b). All ACL injuries (n=53) recorded in regular league matches during three periods between 1989 and 2000 were registered. In addition the floor type in every match was determined based on match schedules. The study showed a higher risk of sustaining an ACL injury on artificial floors compared to wooden floors. In other words, to prevent ACL injuries it might be worthwhile examining measures to reduce the shoe-floor friction, whether through improved shoe designs, floor types or maintenance routines.

The implication of sex differences in ACL incidence has been studied among the above mentioned risk factors. Recently, the focus has been on proprioception and neuromuscular control. Hewett (Hewett et al. 2002) hypothesises in a review that females have three neuromuscular imbalances: Firstly, they seem to be ligament-dominant which refers to absence of muscle control of mediolateral knee motion. During single-leg landing, when pivoting or decelerating the female athlete allows the ground reaction force to control the direction of motion of the lower extremity joints, and the ligaments take on a significant percent of the force. This leads to high forces and high valgus torques to the knee (Hewett et al. 2002). The second imbalance is termed "quadriceps dominance", female athletes preferably activate their knee extensors over their flexors during sports activity to stabilize their knee. The third imbalance is "dominant leg dominance" which is the imbalance between muscular strength and recruitment of opposite limbs, with the nondominant leg often having weaker and less coordinated hamstrings muscles. This imbalance could predispose the non-dominant leg to injury during pivoting or one-leg landing activities (Hewett et al. 2002). A reeducation of the neuromuscular control is Hewett`s proposed solution with the use of neuromuscular training programs.

In spite of these studies, the relationship between gender and neuromuscular control is still not clear and needs further research.

Injury mechanisms

Over the past decades, several studies have been done to understand the anatomy and function of the ACL. Injury surveillance has been done in basketball and soccer in the US, but so far little research has been done on the injury mechanisms. Boden et al (Boden et al. 2000) reported on the mechanisms of 100 video tapes of ACL injuries in different sports, mainly soccer, basketball and American football. A non-contact mechanism was reported in 72% and a contact injury in 28% of the situations. In the non-contact situations most of the injuries occurred at foot strike with the knee close to full extension. In the contact situations the injury occurred as a result of a valgus collapse of the knee (Boden et al. 2000).

In the study of Strand et al (Strand et al. 1990) they observed that the injuries occurred in a plant and cut movement in 36% of the cases and in a turn in 15%. The back players sustained 58% of the injuries and 76% occurred in the attacking phase of the play. Most often, the injury was a non-contact injury, only 1/3 of the injuries occurred in contact with the opponent. However, it is not clear whether contact was with the injured leg, or with any part of the body.

As part of our research program the injury mechanisms in team handball have been analyzed using videotapes of injury situations (Olsen et al. 2003b). We collected 20 videotapes of ACL injuries from female team handball, the videos were digitized and enhanced by creating still, slow motion and enlarged picture sequences of the incident. The videos were then analyzed by three handball and three medical experts. The study showed that the injuries usually occurred in a non-contact plant and cut movement or when landing after a jump shot. The injury mechanism in all cases was forceful valgus-external or – valgus-internal rotation with the knee close to extension, and the injuries seemed to happen when the foot was planted and firmly fixed to the floor (Olsen et al. 2003b). All of the observers of the videos concluded that the ACL ruptured shortly after foot strike, although it is not possible from the video analysis to determine exactly when the ligament ruptures. Obviously, there is a need for further biomechanical studies to obtain a more exact understanding of the injury mechanisms.

Treatment

The ACL injury was first described in 1850 by Stark (Grøntvedt 1996), and the first reconstruction was described in 1917 by Hey Groves using the iliotibial band. In 1937 Palmer reported success with ten sutured ACL injured patients, but this treatment as well as prostethic ACL replacements have later proved to be insufficient alternatives (Andersson et al. 1991; Grøntvedt 1996; Dahlstedt et al. 1990; Engstrom et al. 1993).

The gold standard for ACL reconstructions for the last two decades has been the intra-articularly placed bone-patellar tendon-bone (BPTB) autograft, where the central third of the patella tendon with bone blocks at both ends is used (Eriksson 2001). From the late 1980s the orthopedic surgeons have used the arthroscopic reconstruction technique, with the benefit of less surgical morbity in the early postoperative period (Clancy and Smith 1991; Rosenberg and Graf 1992).

The treatment options after an ACL injury are either conservative or surgical. There is a general agreement that a proper rehabilitation is necessary in both cases. The rehabilitation is almost identical, but the surgically treated group usually needs longer time (6-12 months) to achieve the rehabilitation goals if surgery is not performed (3-6 months). In recent years the increased awareness of the importance of neuromuscular control has changed the rehabilitation programs from strength-based exercises to a greater emphasis on functional rehabilitation with neuromuscular exercises (Wilk et al. 1999).

So far there is no gold standard in ACL rehabilitation; the treatment has changed along with experiences from clinical studies and clinical practice, by orthopaedic surgeons, physical therapists in cooperation with the patients. Shelbourne's accelerated rehabilitation program is mostly a result of patients that did not follow the original protocol. They used their reconstructed knee earlier and more aggressively than prescribed and returned to control with well-functioned knees much earlier than expected (Shelbourne and Nitz 1990). This finding led to a reassessment of the rehabilitation protocol. Now the most aggressive rehabilitation protocols allow patients to start running 4 weeks postoperatively, and to participate in pivoting sports after 3-4 months (Shelbourne and Rowdon 1994). However, the ligament and the muscle strength are at this time still weaker, far from the normal ACL (Arnoczky et al. 1982; Hefti et al. 1991; Risberg et al. 1999a). In addition, the patients have not obtained their neuromuscular control at this point of the rehabilitation (Lephart et al. 1992; Fischer-Rasmussen and Jensen 2000; Fremerey et al. 2001).

Many authors agree that patients in high-level sports and patients in physically demanding occupations should be treated with early surgery after their ACL injury. Inactive patients and patients who are willing to accept a decrease in their activity level should be treated conservatively and then reassessed (Noyes et al. 1980; Zarins and Adams 1988; Warner and Warren 1990; Fitzgerald et al. 2001).

Success following an ACL reconstruction depends on many aspects. First, the operation must be successful, second, the physical therapy most be adequate, and third, the patient must be motivated for a long rehabilitation period. In Norway it is customary to follow the patients for six months, and treatment is without cost to the patients during this period.

Consequences of an ACL injury

There are few follow-up studies examining the long time consequences of an ACL injury, especially in elite athletes. Roos (Roos 1994) examined soccer players three to seven years after an ACL injury and found that 30% were active in soccer after three years compared with 80% in the uninjured control population, after seven years none injured elite players were active independent of type of treatment. Scavenius (Scavenius et al. 1999) found in a study that only two of 24 players returned to pivoting sports after conservative treatment.

Studies examining reinjury risk are few, and they report a wide range of rerupture rates from 0.2-20% (Mitsou and Vallianatos 1996; Sandberg and Balkfors 1988; Otto et al. 1998; Bak et al. 2001). However, these studies represent mixed populations of athletes and non-athletes. The rerupture rate after ACL surgery after return to elite sports in general, and team handball in particular, is not known.

Osteoarthritis (OA) is a possible consequence after an ACL injury whether the patient has surgery or has been treated conservatively. Persons with knee OA suffer from swelling and pain, loss of knee range of motion, and often altered function with diminished muscle strength (Gillquist and Messner 1999). The incidence of knee OA differs from sport to sport. Repetitive loading of the joint with continuous stress may result in micro-trauma and degeneration of the cartilage. The degree of degeneration depends on the amount, type and intensity of the sport participation. In a review, Saxon et al (Saxon et al. 1999) stated that sports activities with high impact loading are associated with higher risk of OA, while sports and activities with low impact loading in general are not associated with a higher risk. Roos (Roos 1994) showed in a study that former soccer players, both with and without former injuries, had increased risk of knee OA. The risk was even more pronounced for elite players. The prevalence of OA was 34% among elite players compared with 11% in non-elite players and 4% in controls.

Both reconstructive surgery and conservative treatment seems to be associated with high risk of developing OA (Sommerlath et al. 1992; McDaniel and Dameron 1983). But the data are not consistent; O`Brian (O'Brien 1993) looked at conservatively treated patients 20 years after injury and found a lower incidence of OA compared to a group of reconstructed patients. Another study showed that only 1% of the patients that had undergone a reconstruction had signs of OA five to nine years after the reconstruction (Mitsou and Vallianatos 1996). While Sommerlath and Gillquist (Sommerlath et al. 1992) found 20% gonarthrosis in ACL reconstructed knees 12 years after injury, an associated meniscus injury increased the incidence of gonarthrosis to 46%.

Gillquist and Messner (Gillquist and Messner 1999) concluded that all available studies show that a high frequency of radiographic changes is the rule rather than the exception after ACL injury or reconstruction.

Data on the long-term consequence of the treatment chosen, operative or conservative, is so far non existent in team handball, and we have limited knowledge about the prognosis for the injured player with respect to the return to sport, the risk of reinjury, future knee function and the risk of OA. These issues were the focus of Paper III.

Prevention

Prevention is the ultimate goal of sports injury epidemiology (Bahr 2002), and as soon as there is evidence that points to an association between certain risk factors and injury it is natural to test this through an intervention (Caine et al. 1996). The risk factors concerning non-contact ACL injuries among females are currently a topic of vigorous debate and intense study in sports medicine. So far preventive research has focused on improving the neuromuscular control of the individual, since this appears to be the most promising modifiable risk factor regarding ACL injuries (Arendt 2001).

After studying the ACL injuries among female basketball players in US for 10 years, Henning concluded that the most common mechanisms of injury were in planting and cutting (29%), straight-knee landing (28%) and one-step stop with the knee hyperextended (26%). He introduced a prevention program consisting of drills where the athletes practiced substituting an accelerated rounded turn off a bent knee for the pivot and cut, landing on a bent knee instead of a straight knee, and finally, a three-step stop instead of one-step stop with the knee hyperextended. Preliminary data in a limited population of basketball players over two years demonstrated an 89% decrease in ACL injury rate (Griffin et al. 2000).

The first intervention study to prevent ACL injuries among male soccer players was performed in Italy (Caraffa et al. 1996). The study included 300 players in the intervention group, who completed a neuromuscular training program, and 300 players in a control group, who practiced soccer as before. The exercises were performed on different types of wobble boards and the players practiced approximately 20 minutes each day with five levels of difficulty. Each phase of training was performed for three of six trainings days, depending of proficiency, and all training sessions lasted for at least 30 days. The players had to demonstrate good skill before progressing to the next level (Caraffa et al. 1996; Cerulli et al. 2001). In this study the intervention group achieved an 86% reduction in ACL injuries compared to the control group (Caraffa et al. 1996).

Soderman et al (Soderman et al. 2000), on the other hand, tried out a similar preventing program in a prospective randomized intervention study where female soccer players practiced on a wobble board. All players in the intervention group were to perform the exercises at home 10-15 minutes each day for 30 days and then three times per week during the season. The control group continued to practice as usual. In this study, they found no significant differences between the groups with respect either to the number, incidence or type of traumatic injuries in the lower extremities.

Hewett et al (Hewett et al. 1996) observed a reduced incidence of severe knee injuries in female volleyball players using a six week jump training program. They focused on changing landing technique to decrease forces by teaching neuromuscular control of the lower extremity during landing. However, although the results are promising the intervention and control group consisted of an uneven number of athletes from different sports. In addition, the number of injuries was low and the study was too small to evaluate the specific effect on ACL injury rates.

Other studies on ACL injuries or lower extremity injury prevention have had a more multifaceted approach in their intervention programs. Heidt (Heidt, Jr. et al. 2000), Mandelbaum (Mandelbaum et al. 2000) and Wedderkopp (Wedderkopp et al. 1999) have all used interventions consisting of warm-up training program, stretching, strength training, plyometrics and sports specific agility training. In the study by Heidt et al (Heidt, Jr. et al. 2000) 42 of 300 female soccer players participated in a 7-week, 20 sessions, individually tailored program to improve speed and agility. Their preseason program resulted in an overall reduction in the number of injuries in general, and of nine ACL injuries at the end of the season, eight were in the untrained group.

In the study by Mandelbaum et al (Mandelbaum et al. 2000), they evaluated the effectiveness of a neuromuscular and proprioceptive sport specific training program in order to reduce the number of ACL injuries among young female soccer players. A video and supplemental literature was given to the participating teams in the intervention group. Fifty-two teams (1041 players) participated in the intervention, which consisted of traditional warm-up, stretching, strengthening, plyometrics and sport specific agility training. They also stressed avoidance of high risk behavior and tried to increase the kinesthetic awareness of the training group. During the season they confirmed two ACL injuries in the intervention group while they had 32 in the control group. There was an overall 88% decrease in ACL injury among the players in the intervention group. Although there was an impressive reduction in injury risk, there is a possibility of a selection bias, since the teams in the intervention group were highly motivated and volunteered to participate in the study.

Wedderkopp et al (Wedderkopp et al. 1999) introduced a preventive program in a randomized prospective study among young female team handball players. The aim of the study was to investigate the effectiveness of an intervention program designed to reduce the number of injuries in young female players. The intervention consisted of the same types of exercises as Mandelbaums program, in addition the players should use an ankle disc for ten minutes at all practice sessions. The results indicated that the intervention program decreased both traumatic and overuse injuries significantly. However, this was a reduction in all types of injuries; they found no significant reduction of knee injuries in the intervention group.

However, no studies had tried out an ACL preventive intervention in team handball, and the promising results from Italian soccer inspired us to test a similar approach in team handball. The high number of ACL injuries and the potential dire long-term consequences of ACL injuries made developing of a preventive strategy an urgent priority. This was the objective of Paper IV.

Aims of the study

The aims of the present study were to examine:

1. The ACL injury incidence in team handball (Papers I & II).
2. The gender differences in ACL injury incidence in team handball, injury mechanisms and possible risk factors, including menstrual status (Papers I & II).
3. The return rate to sport in team handball players, the re-injury rate after reconstruction and clinical outcome 6-11 years after an ACL injury, including the prevalence of radiological changes (Paper III).
4. The effectiveness of a preventive neuromuscular training program on the incidence of ACL injuries among female team handball players (Paper IV).

Methods

Study populations

In paper I all cruciate ligament injuries in the three upper divisions for both male and females during the 1989-91 seasons were recorded. All the ACL injured players (n=87) from this study group were invited to participate in study III six to eleven years after their initial injury. In paper II all elite players during the 1993-1996 seasons were followed prospectively. Finally, in paper IV all female players in the three upper divisions from 1998-2001 were in the study group.

In these studies, the ability to record and verify all ACL injuries is crucial, and we have followed the teams very closely to avoid missing any injuries among the players during the registration periods. We kept in close contact with the team coaches, as well as the team physical therapist, if one existed. In addition, all the players were covered by NHF's compulsory injury insurance policy. This insurance covers the player's expenses for treatment and possible operative costs, so it is very unlikely that any player with an ACL injury did not register their injury. The risk of including any "false positive" ACL injuries is assumed to be minimal, since almost all injuries have been verified arthroscopically, and with the patient's consent we have obtained copies of their hospital records.

Questionnaire

A questionnaire developed by Strand et al (Strand et al. 1990) was used in paper I. It underwent minor changes and was used again in paper II and IV, but the main information always dealt with the injury situation, personal data, training history and menstrual data. In paper I the questionnaire was sent to the injured players and returned to the investigator. In paper II and IV the investigator interviewed the players in person or by phone. During the preparation for paper III a new questionnaire was developed, including questions on rehabilitation and recovery history, return to sport, reinjuries and consequences of the injury. This questionnaire was mainly filled out by phone.

Injury definitions

Total ACL ruptures which occurred during organized handball training or games were registered.

Tests

All the patients in paper III went through a clinical examination by two experienced physicians. In addition the following tests and outcome measurements were used:

1. The KT-1000 arthrometer (MEDmetric, San Diego, California, USA) described by Daniel et al (Daniel et al. 1985) was used to evaluate knee joint laxity in both conservatively and operatively treated patients.

2. Muscle performance tests with isokinetic equipment (Cybex 6000 dynamometer, Cybex-Lumex Inc, Ronkonkoma, NY, USA, or Biodex System 2 Isokinetic Dynamometer Biodex Medical Inc., Shirley, NY, USA) to evaluate the quadriceps and hamstrings muscle performance.

3. Pain was recorded using Lysholm and IKDC evaluating scores.

4. Measures of thigh circumference for recording of muscle atrophy.

5. Osteoarthritis was assessed by radiograph using Ahlbacks (Ahlback 1968) classification.

6. Functional knee tests to measure lower limb performance (Risberg and Ekeland 1994).

7. The Lysholm (Lysholm and Gillquist 1982) and IKDC (Hefti et al. 1993) scores to evaluate the patient's perception of symptoms and function.

ACL injury prevention program

Few studies exists dealing with prevention of ACL injuries in sports, and no study in team handball. When deciding to perform an ACL injury prevention study it was important to develop a program that was applicable to handball, relatively "easy" to carry out and would enhance neuromuscular control. We used the exercises used in the study by Caraffa et al (Caraffa et al. 1996) as model for parts of the program, but also focused on the two injury risk situations seen in paper I & II, the plant and cut movement and the landing after a jump shot. We developed exercises which emphasized a narrower stance with more knee and hip flexion in the plant and cut situation, and exercises focusing on two feet landings with more knee and hip flexion in the jump shot situation. One set of exercises was floor exercises, one set on a wobble board and finally one set on a balance mat. The use of three types of exercises also made it easier to split the team and use five minutes on each type of exercise. After the first intervention season (1999-

2000) we changed the intervention program somewhat to make it more challenging and specific to handball. In addition physical therapists were attached to each team to supervise the training program.

The first intervention season compliance was recorded based on a team basis, the second intervention season compliance was recorded individually for every player throughout the season. To fulfill the compliance requirement the teams or players had to conduct a minimum of 15 ACL injury prevention sessions during the 5-to-7 week program with more than 75% player participation.

Statistical methods

Most data in this study have described the average as arithmetic mean, and the measure of variability as standard deviation (SD), standard error of the mean (SE) or range.

Paired t-tests were used to compare involved and uninvolved legs in paper III. For nominal categorical data a chi-square test was used to determine whether there were significant differences between groups (paper I, III and IV). When comparing small groups in two by two tables, Fisher‘s exact test was used (paper IV). A chi-square test with three degrees of freedom was used to compare the injury risk during four menstrual phases (paper II and IV). A Mann Whitney test was used for ordinal categorical data (paper III). A Mantel-Haenszel test for cohort data with a person-time denominator was used to compare activity type and gender in paper II. Comparisons between rates were tested by a Walds test (paper IV).

One-way analysis of variance was used to test mean differences in continuous variables between different treatments in paper III.

A p-value less than 0.05 was considered as significant.

Ethics

All the studies included in this thesis were approved by the Data Inspectorate and the Regional Ethical Committee for Medical Research. The injured players gave their written consent to participate in the examinations in paper III and to provide medical information from hospital records.

Results and discussion

ACL injury incidence data

In paper I both ACL and PCL injuries were registered prospectively in the three upper divisions for males and females among 3392 players in the 1989-91 seasons. Ninety-three injuries were found, 87 in the ACL and 6 in the PCL. Among women, 1.8% of the players were injured each season compared to 1.0% of the men. In the elite division the risk of injury was considerably higher, 4.5% of the female players suffered a cruciate ligament injury. The cruciate ligament injury incidence was 0.97 injuries per 1000 playing hours for both sexes in the three divisions. The incidence is calculated based on league matches only, training matches and tournament games were not included. In addition, all the PCL injuries occurred in training and tournament matches, which mean that the total ACL injury incidence was 0.97 per 1000 playing hours. In the elite division the incidence was 1.62 injuries per 1000 playing hours among women and 0.54 injuries per 1000 hours among men.

Since the injury incidence was highest at the elite level, we decided to follow the injury incidence in the elite division among men and women prospectively in the next study (Paper II). The injury incidence was followed for three seasons (1993-96) and a total of 28 ACL injuries were found. There were 23 injuries among women, resulting in an incidence (match and training) of: 0.31 injuries per 1000 player hours. The corresponding results among men were five injuries and 0.06 injuries per 1000 playing hours ($p<0.001$ vs women; risk ratio: 5.0). In match the numbers were 1.60 injuries per 1000 playing hours among women and 0.23 injuries per 1000 playing hours among men ($p<0.001$ vs women; risk ratio: 7.0). Thus, these results confirm the gender difference found in the study from Strand et al (Strand et al. 1990) as well as the high incidence seen in paper I. The injury risk seen was comparable with incidence data from basketball and soccer in the US (Arendt and Dick 1995), but higher than the incidence data from soccer in Norway (incidence: 0.10 per 1000 playing hours among females and 0.06 among men) (Bjordal et al. 1997).

In paper I, 75% of the injuries occurred in a competition, an even higher proportion was seen in the elite divisions in paper II: Of the 28 injuries, 24 occurred during competition (0.91 ± 0.19 injuries per 1000 h and four during training (0.03 ± 0.02 injuries per 1000 h; $p<0.001$ vs. competition; risk ratio: 29.9).

Injury mechanism

Paper I and II both shows that the ACL injury is a typical non-contact injury, 90-95% of the injuries occurred without contact between the player and the opponent. This has also been seen in other sports such as basketball and soccer (Arendt and Dick 1995; Hutchinson and Ireland 1995). However, this information is based on the player's recall of the injury situation. In a study by Olsen et al (Olsen et al. 2003a) video analyses of 20 ACL injuries showed that only one injury was a directly knee contact injury. This study confirms that the injuries do not result from a direct blow to the knee, but in six of the cases player contact was involved before the injury, but not to the lower extremity.

Approximately 90% of the injuries occurred in a plant and cut movement or in a landing after a jump shot in both papers.

Player position

In paper I, II and IV the player position of the injured players has been recorded. The standard line-up in team handball is with three back players (43%), two wing players (29%), one line player (14%) and one goalie (14%). In table 1 we have summed up the players positions from the three studies; 112 (60%) were back players, 52 (28%) were wing players, nine (4%) were line players and 15 (8%) were goalkeepers. This means that the relative risk of an ACL injury appears to be higher among back players and lower among goalies and line players. Another trend is that it seems that the proportion of back players is even higher when studying the elite level only (paper II). One possible explanation for this tendency is that the back players have the team position where most plant and cut movements and jump shots are performed.

This higher risk of having an ACL injury related to player position has also been seen in basketball and volleyball. Grey et al (Gray et al. 1985) reported that basketball centers suffer more ACL injuries than their respective teammates. A center executes more jumping and landing than other players on the court. Similarly has Ferretti et al (Ferretti et al. 1992) found that landing after a jump was the most common injury mechanism among volleyball players, and the net players sustained most injuries, and this increased incidence among the forward players was attributed to the constant jumping required of net players throughout the game (Traina and Bromberg 1997).

The back players in team handball perform the most plant and cut movements and probably also most landings after a jump shot. These two situations are the two high risk situations in the play.

Table 1. Distribution of injuries in the different player positions. Data from paper I, II & IV

Player position	Paper I*	Paper II**	Paper IV***	Total n= 188
Back player	50 (54%)	23 (82%)	39 (57%)	112 (60%)
Wing player	28 (30%)	5 (18%)	19 (28%)	52 (28%)
Line player	5 (5%)	0	4 (6%)	9 (4%)
Goalkeepers	10 (11%)	0	5 (7%)	15 (8%)

**Three top level divisions, male and female, **Elite division, male and female, ***Three top level divisions, female*

Menstrual data

Paper II and IV include data on the player's menstrual cycle status at the time of the injury. In paper II the number of observations was low (n=17), so the results should be interpreted with caution. In paper IV we had 46 players with a reliable menstrual history, and the same distribution as in paper II was seen in this study. Figure 4 shows the pooled results from the two papers, and the menstrual phase (day 1-7) seems to be the high risk period.

There was a significantly higher risk of suffering an ACL injury during the menstrual phase ($p=0.002$, chi-square$_{3\ d.f}$). These results are different from the study by Woitys (n= 65) (Wojtys et al. 1998; Wojtys et al. 2002) who found a significantly higher percentage of ACL injuries during midcycle (ovolatory phase) and less injuries during the luteal phase (day 15-28) of the menstrual cycle. They also found that oral contraceptives diminished the significant association between ACL tears distribution and the ovolatory phase. Wojtys group used a slightly different classification of the menstrual cycle than in our studies; follicular phase (day 1-9), the ovulatory phase (day 9-15) and luteal phase (day 15-28). One strength of their study is that they had blood samples from the injured players, and their classification of menstrual cycle status was based on hormonal measurements, not just player recall.

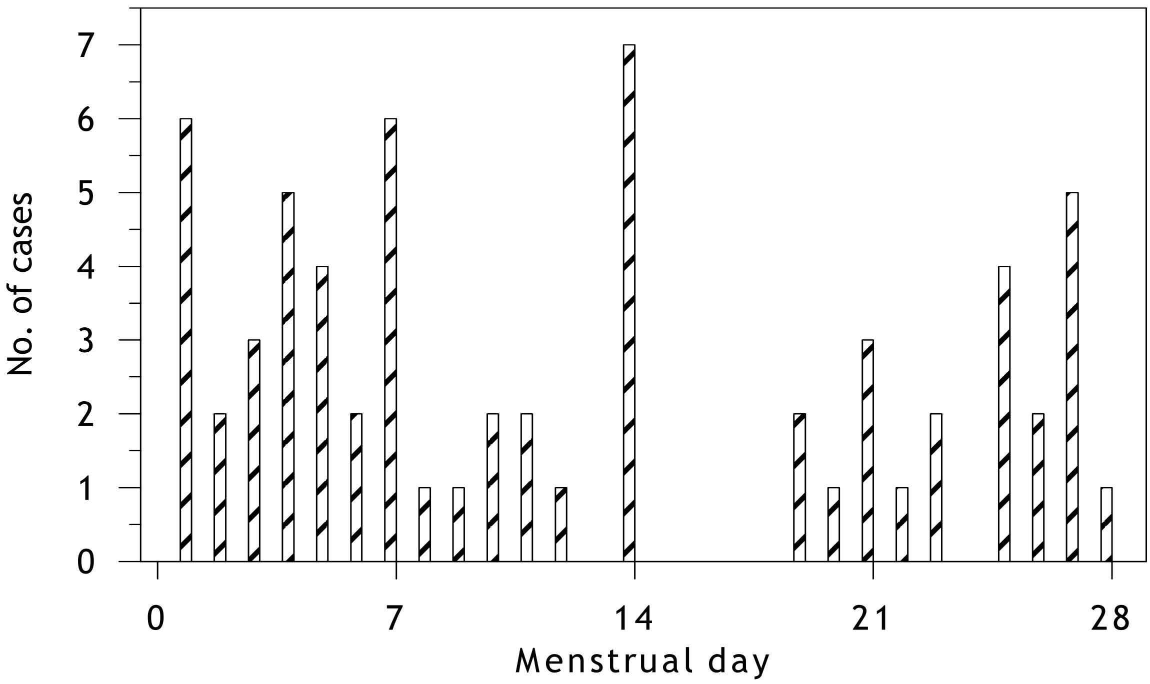

Figure 4. Distribution of the number of ACL injuries in relation to menstrual day (n=63). Menstrual data from study II and IV.

The relationship between the use of oral contraceptives (OC) and ACL injuries has also been studied, with the hypothesis that OC should be protective for the player. Arendt concludes in a review that women using OC may be less susceptible to musculoskeletal injuries compared with non-contraceptive users (Arendt 2001). Recent data has demonstrated that the level of relaxin is increased with the use of OC (Wreje et al. 1995). This, and the information that administration of relaxin and estrogen increases knee stiffness versus estrogen alone in mice, has further confounded the association between these hormones and ACL injuries (Toth and Cordasco 2001).

In our data as many as 36 (eight in study II and 28 in study IV) of the injured players used OC, but we cannot assess the significance of this, since we do not know the proportion of OC users among the non injured players. Nevertheless, the data concerning the risk of suffering an ACL injury in relation to menstrual status are not yet consistent, and further studies are necessary to determine whether the use of oral contraceptives protects against an ACL injury or not.

Injury consequences

The follow-up study was performed to address the consequences of an ACL injury among team handball players. No other studies were available examining this aspect of the injury. Having an

ACL injury has not been seen as a cause to terminate the handball career and few have questioned if a return to high level pivoting sport is wise in relation to long term knee health. The high re-rupture rate, (22%), (10% BPTB, 8% primary repairs, and 4% unknown procedure), found in our study, was unexpected, but recently Drogset & Grøntvedt (Drogset and Grontvedt 2002) have published an 8-year follow up of ACL reconstructed patients. They studied the long term outcome after ACL reconstruction (BPTB) with and without a ligament augmentation device. They found that 11 out of 94 (12%) patients had a rerupture of their reconstructed knee. All reruptures occurred in pivoting activities, in handball (three), soccer (two), unknown (two), activity at home (two), activity at work (one) and one as a result of postoperative infection (Drogset and Grontvedt 2002). Their rerupture rate with BPTB graft is similar to our results (10%). They also found that 15 (16%) of the patients had a rupture of their opposite ACL, but they do not present data on whether this was a sport specific injury or not. This rate of ruptures of the opposite limb was also seen in our study, six players (9%) injured their ACL, all when playing team handball.

One possible explanation of the high rerupture rate and OA found in our follow-up study could be that the operative technique in the beginning of the 90‘s was not as good as contemporary surgery. Whether better results can be expected now, will not be known until new follow-up studies have been performed in 10-12 years. In our study, surgery had been carried out in many hospitals by many different surgeons and we did not know the exact operative technique. In the study by Drogseth & Grøntvedt (Drogset and Grontvedt 2002) all patients was operated at the same hospital and they used one of two operative methods (arthroscopic BPTB reconstruction with or without augmentation), and a notch plasty was performed on the patients. Despite this “controlled” situation they had at least as high a rerupture rate as we did. Since all of the ruptures occurred in pivoting activity (handball in three cases) one could ask if this is “the natural history” after an ACL reconstruction when patients are doing pivoting activities.

Our finding of a quite high risk of OA in this study population after the initial injury is supported by the findings from many studies (Noyes et al. 1983), (Sherman et al. 1988), (Drogset and Grontvedt 2002). Drogseth & Grøntvedt (Drogset and Grontvedt 2002) found that almost half of the patients had developed radiological changes eight years after the ACL reconstruction, which is similar with our results on team handball players, whether they were operatively treated or not.

Not only are the high level of reinjuries and the high rate of OA dramatic, but so is the high proportion of other problems the players has reported in the follow-up study. Nearly half of the players reported problems with instability, pain or reduced ROM, and 25% of the players had work-related problems due to their knee injury. Since a high proportion of the players returned to team handball (about 90% at the same or lower level in both conservative and operatively treated groups) one might ask if it is recommendable to continue to play team handball after an ACL injury. As early as in 1970 Kennedy stated that "the ACL tear is the most common cause of the ex-athlete" (Fowler and Snyder-Mackler 2001). However, the number of ACL injuries has increased since his statement, which probably was meant as a "conclusion" of the "state of the art" at that time, with operative techniques and rehabilitation programs that were insufficient. One might ask if a reasonable advice to the injured players would be to quit top level team handball/pivoting sports, if long-term knee health is the primary concern. Studies have shown that if you injure your ACL there is a 10% chance of injuring the opposite one, and those who have a sibling with ACL injury also have a 10% chance of sustaining the same injury compared to a less than 1% chance in the general population (Fowler and Snyder-Mackler 2001).

We must be careful how we interpret the results from paper III. Perhaps today's surgery and rehabilitation now is better than previously, but we do not know what the long-term results of contemporary surgery will be. Nevertheless, physicians and PT‘s working with this patient group should emphasize giving adequate information of possible consequences of a return to play so the players can make an informed decision with all necessary information available, including the caveats related to future risk of knee problems and OA.

Prevention of ACL injuries

Starting an ACL prevention study was a natural consequence of the information the three former studies provided. A high incidence among female players and quite dramatic consequences over time made it clear that an ACL prevention study was necessary. Methodologically we knew that if we were to detect a 50% reduction in the number of ACL injuries, we needed 1000 players each of the control and intervention groups in a randomized controlled trial. This represents twice as many players as what was available in the three top divisions in Norwegian team handball. A randomized controlled study was not possible in Norway. This was caused by the fact that the teams in the lower divisions play and practice too little to be included in an intervention. Another possibility would be to test the intervention in a Scandinavian study, but this was not possible at the time for economical and practical reasons. Consequently, we choose to use one season as baseline and then the two following seasons for our intervention.

The results showed a trend towards a reduction in the number of ACL injuries during the intervention. This was not statistically significant ($p=0.15$ for all divisions and $p= 0.06$ for the elite division), but we found a significant reduction in injury rate in the group of elite players who performed the intervention program as intended compared with those who did not.

The number of non-contact injuries was reduced from 18 injuries in the control season to seven in the second intervention season ($p=0.04$). This is promising, since the intervention program was designed to prevent the non-contact injuries by improving neuromuscular control.

The incidence was followed closely during the ACL prevention study in the 1998-2001 seasons (Paper III). The objective of the study was to assess the effect of a neuromuscular training program on the ACL incidence among female players in the three upper divisions. In Figure 3 the ACL injury development has been illustrated from the control season (1998-99) to the second intervention season (2000-2001). In addition, data from a follow-up season were we did not do any intervention have been included to further illustrate the development (Myklebust et al. 2002). It shows that after a successful intervention, pressure must be kept on to keep the ACL incidence from rising.

In the control season (1998-99) the incidence was 1.48 per 1000 playing hours for all three divisions and 2.79 in the elite level. The incidence decreased to 1.14 and 1.05 after the first intervention season (1999-2000) and then 1.09 and 1.31 during the second intervention season (2000-2001). After the prevention study was finished the teams were followed to see in what way the teams followed the training program and survey the injury incidence. We found an increasing number of ACL injuries in the follow-up season, with an incidence of 1.37 per 1000 playing hours for all divisions and 2.62 in the elite division. Approximately 2/3 of the teams had not followed the program after the intervention was finished and among the 20 ACL injured players, only one player used the exercise program from the intervention seasons (Myklebust et al. 2002).

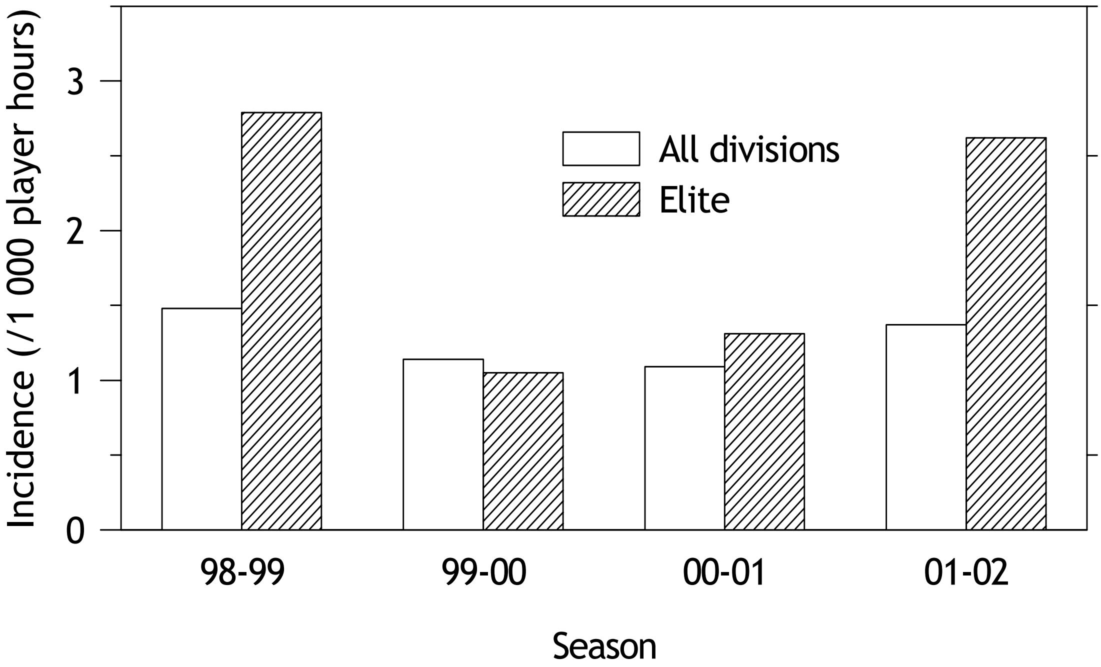

Figure 3: ACL incidence data during the seasons 1998-2002.

The high incidence changes we experienced during the ACL injury prevention period and the year after the intervention might be natural variation. However, studies from soccer and basketball in US have seen a slight increase in ACL incidence from the beginning of the 90's to 2000 (personal communication Julie Agel dec 02, NCAA data). We do believe that a similar pattern could be the case in Norway. The 1998-2002 period could indicate that the prevention program have worked, but a continuous surveillance of the incidence is necessary to confirm this.

Compliance

This study clearly shows the importance of obtaining compliance data when performing an intervention study. Without this information we had not been able to explain the results that we saw among the elite players. No other ACL prevention studies have recorded compliance as a part of their methodology, so they cannot predict the exact effect of the training response. When we decided the compliance criteria we used Blumenthal et al (Blumenthal et al. 1982) 75% participation in practice as our criterion. The number of ACL training practices had to be at least 15, and they had to be performed for 5-7 weeks to meet our compliance criteria. However, we don't know what the minimum amount of practice is necessary to achieve an effect. We chose five to seven weeks, since studies have suggested that this is the minimum time needed to have an effect on the neuromuscular "performance" (Caraffa et al. 1996; Cerulli et al 2001; Hewett et al. 1999). Also, we still don't know if the effect could have been better with a longer and more intensive practice period.

The ACL injury prevention program

The main focus of the prevention program was to improve awareness and knee control during standing, cutting, jumping, and landing. The players were encouraged to be focused and conscious of the quality of their movements, and with emphasis given to core stability and hip and knee position in relation to the foot – the "knee over toe" position.

The exercises were developed based on the exercises used by Caraffa et al (Caraffa et al. 1996) on different wobble boards. We included exercises on a balance mat to further challenge neuromuscular control, and finally floor exercises thought to be applicable to team handball. The focus on the knee position – "knee over toe" – was supported by data from Ebstrup and Bojsen-Moller (Ebstrup and Bojsen-Moller 2000) and Olsen et al (Olsen et al. 2003a). Their video analyses of ACL injuries from team handball indicate that it could be beneficial not letting their knee sag medially or laterally during plant and cut movements or when suddenly changing speed. We also focused on two-feet landing after jump shot with the emphasis on hip and knee flexion based on the data of Hewett et al (Hewett et al. 1996) from volleyball. We also tried to influence the player's way of performing the two feet plant and cut movement, aiming towards a narrower stance as well as the knee-over-toe position. We do not know whether it is possible to detect any change in technique in an intervention like this, and perhaps this is difficult in mature players. This type of program should be tested in young players, giving them neuromuscular challenges as a natural part of the practice and a focusing on a more "ACL friendly" technique.

The prevention program is multi-faceted and addresses many aspects of risk for injury, aspects as agility, balance, proprioception, awareness of vulnerable knee positions and playing technique. By the time we started the intervention we did not know which part of the program that could be effective in preventing ACL injuries.

However, during the first intervention season 35 female handball players from two of the elite division teams participated in a study investigating the physiological effects of the ACL injury prevention training program on balance, proprioception, muscle strength and lower limb function (Holm et al. 2003). The players were tested pre training, eight weeks and 12 months after the ACL preventive training started. The players went through the following tests; Knee joint laxity by KT-1000 arthrometer, balance was tested using the KAT 2000, knee kinesthesia was conducted by measuring the threshold to detection of passive motion using a proprioception device, quadriceps and hamstrings muscle strength was tested using a isokinetic dynamometer, and finally three functional knee tests (the one-leg hop test, the triple jump test and the stairs hopple test) were used to evaluate general lower limb function.

The main results was that there was a significant improvement in dynamic balance between test 1 and test 2, with a balance index of 924 (±225) and 778 (±174), respectively ($p=0.01$). In addition, we found that the improvement in dynamic balance was maintained 1 year post training. We found no statistically significant changes for static balance. The results from this study showed a benefit on dynamic balance from the neuromuscular preventive training program, while there was no detectable effect on muscle strength or proprioception (Holm et al. 2003). One interesting aspect of this is that the prevention program gives measurable results on a quality that the program was designed to challenge, the dynamic stability. So far we do not know the possible effects on landing forces, knee moments, technique and other relevant neuromuscular parameters. These aspects need further investigation.

Evaluation methods

One crucial point in epidemiological studies is related to the injury registration: was it good enough in our studies? In all three studies (Paper I, II and IV) the teams were followed prospectively and we kept in close contact with team coaches and medical staff throughout the study periods, and they were requested to report ACL injuries as soon as they occurred. Also, all insurance claims were examined for additional ACL injuries. Even so, there is always a possibility that an injury may have been overlooked. However, an ACL injury usually causes pain, swelling and disability, and it is doubtful that a player may have developed an injury without the need for medical follow-up. In addition most of the injuries were verified arthroscopically. It is therefore unlikely that there were "false positive" or overlooked ACL injuries during the prospective studies.

The evaluation tests used in Paper III was the most commonly used tests at the time we started the follow-up study. Studies have shown a weak correlation between process measures like radiographs or laxity tests and patient-related measures such as pain, function and activity level (Roos 1999). We wanted therefore to use tests that embrace several aspects of the patient's possible outcome.

Snyder-Mackler et al (Snyder-Mackler et al. 1997) tested the anterior displacement of tibia relative to the femur in two groups of conservatively treated ACL patients. One of the groups had returned to high level sports activity, the other was not able to continue sport. There were no differences in anterior displacement measures between the groups. They concluded that there were no correlation between instability and function. This is in line with Sernert (Sernert et al. 2001) who showed that KT 1000 measurements did not correlate with the subjective, objective and functional evaluation scores in a two-year post operative follow-up of ACL reconstructed patients. KT 1000 measures should be done by the same examiner since the reproducibility between two experienced examiners has been seen as fair (Sernert et al. 2001). In our study we used the same examiner in all the tests.

The reproducibility (or reliability) and validity of isokinetic muscle strength measurements is important. Modern isokinetic equipment offers high sensitivity, so device error is not a big problem (Dvir 1995). If the calibration routines are closely followed, the systems are very reliable (Holm 1996). Dvir (Dvir 1995) have stated, in his book concerning validity, that isokinetic testing are valid for, among others, ACL deficiency. Several studies have shown a positive correlation between isolated isokinetic results and functional tests measures such as running, cutting and hopping (Tegner et al. 1986; Wiklander and Lysholm 1987; Barber et al. 1990; Noyes et al. 1991; Risberg and Ekeland 1994). Risberg et al (Risberg et al. 1993) showed a positive correlation between the stair hopple test, the triple jump test and the quadriceps strength measured isokinetically. Natri et al (Natri et al. 1996) have shown in a follow-up of ACL injured patients that patellofemoral pain and flexion deficits were most frequently and significantly associated with the strength deficits measured by isokinetic testing. Both the isokinetic and functional tests were performed by an experienced PT.

Several functional tests are described in the literature to measure lower limb performance (Greenberger and Paterno 1995; Noyes et al. 1991; Wilk et al. 1994). Risberg et al (Risberg and Ekeland 1994; Risberg et al. 1999c) found that the one leg hop, the triple jump and the stairs hopple tests are sensitive in detecting changes over time in the late rehabilitation phase, and to detect knee instability. All of these tests are one-leg tests that make us capable to detect differences between injured and uninjured leg. Bolgla (Bolgla and Keskula 1997) tested the reliability of single hop, triple hop and 6m timed hop test. He concluded that clinicians could use functional performance testing to obtain reliable measures of lower extremity performance when using a standardized protocol. In paper III we used the same tests as Risberg et al (Risberg and Ekeland 1994; Risberg et al. 1999c).

The Lysholm score is probably the most commonly used score for evaluating knee injuries. The Lysholm score reliability and validity has been tested and found excellent (Marx et al 2001), but it is found to be less sensitive for ACL patients compared with patients with patellofemoral pain syndrome or lateral ankle sprains (Bengtsson et al. 1996).

The IKDC evaluating form has been found to have low sensitivity to clinical changes over time, but have satisfactory results concerning criterion validity. The graded IKDC seems to have a satisfactory relationship to other commonly used outcome measurements, so IKDC is a good tool for testing at one follow-up (Risberg et al. 1999b; Irrgang et al. 1998).

We also need tools to evaluate the patient's ability to return to high level sports or leisure activities, tools that capture the many qualities needed for many sports activities. Until now we have had to use a combination of tests and measurements to achieve a reliable assessment of patient function, especially in relation to the ability to return to high demanding pivoting sports.

Conclusions

1. The ACL injury incidence in team handball is high, up to 1.60 ACL injuries per 1000 playing hours among women and 0.23 among men.

2. The incidence of ACL injuries is five-fold higher among elite female players compared to men, while at the lower levels the risk for female players is twice as high as for the males. The risk of getting an ACL injury is 30-fold higher during competition than during training. Most of the injuries occur in a non contact situation when the players performs a plant and cut movement in the attacking part of the play. Many of the injuries among women occur the week prior to or after the onset of menses.

3. The return rate to sport at pre-injury level was high in both the operated group (59%) and the conservatively treated group (82%). The re-injury rate was high, 22% of the players sustained a new ACL injury. About half of the players in both groups complained of pain, instability or reduced range of motion 6-11 years after their ACL injury, and nearly half of the players had radiological signs of osteoarthritis.

4. There was a reduction of the incidence of ACL injuries from the control season to the second intervention season among the elite players who completed the training program. The neuromuscular training program seems to work, provided a minimum of 15 practices in the intense training period and once a week until the season is completed.

Future studies

Several questions have arisen through the study period and should lead to new studies:

- Epidemiological studies should continuously be done to monitor the trend in ACL injuries among men and women, but also include younger players
- The consequences of injury should be further studied in follow-up studies, with particular attention given to the effects of return to play on future risk of OA and knee function
- Biomechanical studies of the plant and cut movement should be done to examine if there are differences between male and females in the way they perform the movement
- Studies to determine the individual effect of each component of the neuromuscular training program used in study IV

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Papers I-IV

Paper I

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Registration of cruciate ligament injuries in Norwegian top level team handball. A prospective study covering two seasons

Myklebust G, Maehlum S, Engebretsen L, Strand T, Solheim E. Registration of cruciate ligament injuries in Norwegian top level team handball. A prospective study covering two seasons.
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All cruciate ligament injuries in the three upper divisions for men and women (3392 players) in Norwegian team handball in the 1989–90 and 1990–91 seasons were registered. A questionnaire was mailed to all injured players. Ninety-three cruciate ligament injuries were registered; 87 in the anterior cruciate ligament (ACL), and six in the posterior cruciate ligament (PCL). Among women, 1.8% were injured compared with 1.0% of the men. In the first division, the risk of being injured was considerably higher: 4.5% of the players had a cruciate ligament injury. There were 0.97 cruciate ligament injuries per 1000 playing hours in the three divisions taken together. Seventy-five per cent of the injuries occurred during games. Ninety-five per cent involved no contact between players. Activities in which the friction between shoe and floor was significant caused 55% of the injuries. Injuries caused by running into another player contributed to only 5% of the injuries. No significant differences were observed in injury incidence during matches between different types of floors (parquet, Pulastic and other synthetic surfaces).

G. Myklebust[1], S. Maehlum[2], L. Engebretsen[3], T. Strand[4], E. Solheim[4]

[1]Norwegian Institute of Sports Medicine, Oslo, Norway, [2]National Sports Center, Oslo, Norway, [3]Department of Orthopedic Surgery, University of Minnesota, USA, [4]Department of Orthopedic Surgery, University of Bergen, Norway

Key words: etiology; cruciate ligament injuries; European team handball

Grethe Myklebust, PT, Norwegian Institute of Sports Medicine, Sognsvn. 75f, Ullevaal Stadion, Oslo, Norway
Tel.: 22230043; fax: 22230048

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Team handball is a high-intensity sport with frequent physical contact between players. In a retrospective study, Strand et al. (1) found a high incidence of anterior cruciate ligament (ACL) injuries in team handball in Norway. An increasing incidence of cruciate ligament injuries has been reported in team handball as well as in other ballsports such as basketball, volleyball and soccer (1–6). In addition to the increased incidence of ACL injuries, some authors have suggested that females in general sustain more injuries than males (5,7,8). The present study was designed to examine cruciate ligament injuries in high-level Norwegian team handball. The specific goal of the study was to evaluate the incidence of such injuries in the three upper divisions, and possible gender differences in the prevalence of these injuries.

Material and methods

Each team in the three upper team handball divisions for men and women (212 teams) participated in the study during the 1989–90 and 1990–91 seasons. Each squad was assumed to consist of 16 players, since this is the number of players in the squad in all international competitions. Thus the total number of players was 3392. The coaches and players received information concerning the study through the Norwegian Handball Federation and direct mailing, and were asked to report all knee injuries to the study group. In addition all clubs were mailed a reminder during the registration period. Information about the injuries was obtained through several channels; from the players themselves, from the coaches, from hospitals, or from the insurance company where all the players in Norway are insured. The primary investigator (GM) kept in close contact with all teams by mail and telephone to ensure that all injuries were reported. All the suspected cruciate ligament injuries were subsequently diagnosed by orthopedic surgeons or physicians specialized in sports medicine. All the ACL injuries were operated on, as well as one of the posterior cruciate ligaments (PCL) injuries. Thus almost all the diagnoses had been verified peroperatively. All the players who were found to have sustained a cruciate ligament injury received a questionnaire. The questionnaire contained questions regarding gender, age, time of injury, player position and the mechanism of injury.

The number of playing hours was calculated using seven players on each team. Since the matches last 2×30 min this means each match represents 14 player hours. The injury risk per 1000 playing hours was calculated using only the regular league matches. In addition, teams played a few cup and training matches, but these were not included. The number of player hours on the different types of floor material in matches was calculated using the Norwegian Handball Federation's schedule of league matches.

Statistics

The chi-square test was used for comparing differences in the percentage of matches in which one of the players sustained an injury of the cruciate ligament, between men and women and between players of the three different divisions. A P-value less than 0.05 was regarded as significant.

Results

All the players sustaining a cruciate ligament injury during the two seasons returned the questionaire; the response rate was therefore 100%. The average age of the injured players in all three divisions was 21.3 (16–34) years for women and 23.8 (16–36) years for men.

Table 1 shows the average age of the injured female and male players in the different divisions. Ninety-three cruciate ligament injuries were observed. Eighty-seven of the injuries occurred in the ACL, six in the PCL. Fifty-nine injuries (63%) occurred in females (54 ACL injuries and five PCL injuries); 34 (37%) were found in males (33 ACL injuries and one PCL injury). All five PCL injuries in women were seen in the first division. The one PCL injury in men was observed in a second division player. On average 1.4% of the players sustained a cruciate ligament injury each season. An identical number of female and male players participate in divisions 1–3. In the females 1.8% of the players suffered a cruciate ligament injury per season, compared with 1.0% of the males. There were 0.97 cruciate ligament injuries per 1000 player hours in all three divisions together.

Table 1. Age (years) of injured players according to sex and division

Gender	Division 1	Division 2	Division 3
Females	21.9 (17–27)	19.4 (17–26)	22.6 (16–34)
Males	22.5 (17–25)	24.0 (20–36)	25.1 (16–36)

Table 2. Injury risk in matches (injury per 1000 playing hours)

Division	Women	Men
1	1.62	0.54
2	1.82	0.84
3	0.72	0.27

Table 3. Cruciate ligament injury per season by division and gender

Division	Gender	Incidence (%)
1	Female	4.5
	Male	2.2
2	Female	2.0
	Male	2.0
3	Female	1.3
	Male	0.6

Table 4. Distribution of injuries in the different player positions (%)

Back players	54
Wing players	30
Line players	5
Goalkeepers	11

Table 2 shows the number of cruciate ligament injuries/1000 player hours sustained during games by gender and division.

Table 3 shows the total incidence of cruciate ligament injuries by gender and division (i.e. for both matches and training sessions.) The incidence was twice as high in females compared with males in the first as well as in the third division. In the second division the incidence was identical among the two sexes.

The consequences of the players' position on the incidence of cruciate ligament injuries is demonstrated in Table 4. The back and wing players sustained 84% of the injuries. Ninety-five per cent of the injuries occurred without any contact with the opposing player. Fifty-five per cent of the injuries occurred in situations where the friction between shoe and floor may have played a considerable role, as in cutting or fake movements. Thirty per cent of the injuries occurred while landing after a jump. Sixteen per cent of the injuries occurred in situations that the player judged to be 'high risk situations'. Eighty-four per cent occurred in situations that the players perceived as 'low risk' as far as injuries were concerned. Seventy-eight per cent of the players were in contact with the ball when injured. Fifty-three per cent were moving at high speed, 33% at slow speed and the remaining 14% were standing still when the injury occurred.

Seventy-five per cent of the injuries occurred during games, and 25% during training sessions. In division 1 half of the injuries occurred during matches, while the corresponding numbers in division 2 and 3 were 73% and 77% respectively. This occurred in spite

Table 5. Floor types and injuries during games and training

	Game	Training
Parquet	21	1
Pulastic	18	13

of the fact that the players spend almost 10–15 times more time training than playing matches.

Fifty-three per cent of the injuries occurred during the first half of the game. Ninety per cent of the injuries occurred while the team was attacking, and only 10% when the team was in defence.

Parquet and Pulastic are the two most commonly used floor materials in Norway. Table 5 shows that the number of cruciate ligament injuries during games were almost identical on the two floors. The number of playing hours on the two surfaces were also almost the same. The number of training hours on the different floors is not known.

The percentage of matches in which one of the players sustained an injury of the cruciate ligament was significantly higher in female (0.77%) compared with male matches (0.31%; P=0.01), and in players of the two upper divisions (0.87%) compared with players of the third division (0.35%; P<0.01).

Discussion

The results of this study reinforce the high cruciate ligament injury incidence reported previously (1, 2, 3, 5, 6). Furthermore, our report indicates that top-level females injure their cruciate ligament twice as often as males in this particular sport. This has previously been reported in sports like soccer (5, 6, 7, 9), basketball (2, 7, 9) and gymnastics (7).

The response rate in the present investigation was very high: 100%. Only players with a known cruciate ligament injury were given the questionnaire, and there may have been players with unrecognized cruciate ligament injuries that were not included. However, the medical staff for the teams in division 1 and 2 should be able to pick up these serious injuries. In the third division the teams are spread out all over the country and generally have a less active medical support. There may therefore have been some unrecognized injuries in this division. However, we believe that very few remained undetected since our investigation received broad press coverage all over the country, making coaches, players as well as local physicians more aware of these injuries.

The cruciate ligament injury rate was higher in the upper two divisions. We feel comfortable that the reported injuries represent the true number in divisions 1 and 2, but, for reasons stated above, are somewhat more uncertain about the numbers in division 3. However, even with this uncertainty the study suggests two- to fourfold more injuries in division 1 compared with the lower divisions.

The observed number of cruciate ligament injuries /1000 player hours was higher than those previously published (5, 7, 9). The number was higher in the second division than in the first division for both sexes. The overall incidence of cruciate ligament injuries in division 1 was much higher in the females and higher in the males than in division 2. More players were injured during training in division 1. This indicates that they train more, and with a higher intensity.

The injury risk was much higher during games than during training. Seventy-five per cent of the cruciate ligament injuries occurred during games. Similar data have previously been published for soccer (6) and volleyball (3). This is somewhat puzzling, since the players spend about 10–15 times more time training as playing matches. The reason may be that the intensity is much higher during games than during training. The relatively high incidence of injuries in training in division 1 could be explained by the fact that in top level teams the intensity of the training is higher than in divisions 2 and 3.

There were almost as many injuries during the first as during the second half of the games. Fatigue, therefore, does not seem to be a major factor in the etiology of these injuries. However, it should be noted that we did not ask the players how long they had actually played before they were injured.

The etiology of the high rate of cruciate ligament injuries in females compared to males is not clear. Numerous hypotheses have been offered: differences in ligament laxity (10); bony anatomy (11–13); muscle strength (14); proprioception and skill level (10) have all been suggested in the literature. However, few hard data exist regarding the gender-specific mechanism of cruciate ligament injuries. Muscular weakness has been reviewed with no conclusive evidence pointing to a gender difference (15).

It should be noted that contact with other players does not seem to be important. This has also been observed in basketball (9, 16). Supporting this is our finding that the majority of the injuries occurred in situations that were not perceived by the players as dangerous.

However, it has been reported (17) that high speed and many violent contacts in a small playing area are shown to be associated with increasing injury risk. Thus, even though the true contacts are not the usual reason for ACL injuries, the problem behind this may be that the players move against each other with high speed in a limited area.

Most injuries seemed to occur in situations where the friction between shoe and floor is of importance. Thus 90% of the injuries were found to occur when the teams were attacking; a part of the game in which most of the fake movements are performed. Likewise, the observation that the back and wing players sustained 84% of the injuries supports this notion, since these players perform most of the fake movements. However, identical movements are carried out by male handball players with half the incidence of cruciate ligament injuries.

Conditioning and experience have been suggested as possible variables in the multifactorial mechanism associated with an increased cruciate ligament injury rate in female team handball players. However, the elite female handball players in Norway (division 1) train at least as hard as the men, and they have as many years of experience with handball. These factors therefore seem unlikely to be of great importance. However, even though they train equally hard as the men, women may still be weaker and less coordinated than their male counterparts.

Another possible etiological factor implicated as a reason for cruciate ligament failure has been the anatomy of the intercondylar notch (ICN); i.e. a narrow notch shape and size has been suggested as a contributing factor to cruciate ligament injuries. However, no conclusive evidence can be drawn from the literature so far regarding gender variations in relation to ICN indices. In one study (11) no differences were observed; while other investigators have found a more narrow notch in females compared with males, and conclude that this may mean that females have a higher risk for ACL injury (12, 13). Due to their less muscular development and their lower extremity alignment differences, females probably rely more than men on the ACL and less on hamstring control. This may result in a higher incidence of cruciate ligament injuries.

In conclusion, the very high incidence of cruciate ligament injuries in team handball suggested by retrospective studies is supported by the present study. Females have twice the risk as males for such injuries. The risk is also higher in the higher divisions. The majority of injuries occur without contact with the opposing player in situations where the friction between the foot and the floor is of importance.

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Paper II

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A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball

G. Myklebust[1,2], S. Mæhlum[2,3], I. Holm[4], R. Bahr[3]

[1]Norwegian Institute of Sports Medicine, [2]National Sports Centre, [3]Norwegian University of Sport and Physical Education, and [4]National Hospital Orthopaedic Centre, Oslo, Norway

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The purpose of this study was to examine gender differences in the incidence of anterior cruciate ligament (ACL) injuries in a population of high-level team handball players. We also wanted to examine injury mechanisms and possible risk factors for ACL injuries, including menstrual status. The study was done prospectively during the 1993–94, 1994–95, and 1995–96 seasons. We found 28 ACL injuries, 23 among women (incidence: 0.31±0.06 injuries per 1000 player hours) and 5 among men (0.06±0.03 inj./1000 h; $P<0.001$ vs women; risk ratio: 5.0). Of the 28 injuries, 24 occurred during competiton (0.91±0.19 inj./1000 h; women: 1.60±0.35 inj./1000 h; men: 0.23±0.13 inj./1000 h; $P<0.001$ vs. women; risk ratio: 7.0) and 4 during training (0.03±0.02 inj./1000 h; $P<0.001$ vs. competition; risk ratio: 29.9). Nearly all the injuries ($n=25$) occurred in non-contact situations when the players performed high-speed plant-and-cut movements which they were well accustomed to. A reliable menstrual history could be obtained in 17 of the 23 cases among females. Five of the injuries occurred in the menstrual phase, 2 in the follicular phase, 1 in the early luteal phase and 9 in the late luteal phase (chi-square$_{3\ d.f.}$= 13.2; $P<0.01$). The results suggest that there may be an increased risk of ACL injury during the week prior to or after the start of the menstrual period.

Key words: ACL injury; etiology; European team handball; menstrual status

Grethe Myklebust, Norwegian Institute of Sports Medicine, PO Box 3808 Ullevål Hageby, 0806 Oslo, Norway

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Studies based on the National Collegiate Athletics Association Injury Surveillance System have shown that female athletes are at increased risk for injuries compared to men in certain US sports, i.e. basketball, soccer and gymnastics (1, 2). The same studies show a notable gender difference in the rate of knee injuries, in particular injuries involving the anterior cruciate ligament (ACL) (1, 2). Arent & Dick found that the rate of ACL injury among women was 2.4 times higher in soccer and 3 times higher in basketball compared to men (2).

The reasons for these gender differences are unknown. A number of hypotheses have been suggested, e.g. differences in lower extremity alignment, notch dimensions, ligament size, muscle strength and coordination, level of skill and conditioning. As reviewed by Arent & Dick recently (2), no firm conclusions can be reached regarding any of these factors, and there is clearly a need for further research.

In addition, it has been suggested that there may be sex differences in ligamentous laxity, possibly related to cyclic hormonal effects (1), but there are no studies supporting this hypothesis. However, it is interesting to note that Møller-Nielsen & Hammar (3) found that women soccer players were more susceptible to injuries during the premenstrual and menstrual phases compared to the rest of the menstrual cycle. They also observed that women using oral contraceptives had a lower injury rate than those who did not. However, this study examined traumatic injuries in general, and did not include specific data on knee injuries or ACL injuries.

The aim of this study was to examine gender differences in the incidence of ACL injuries in a population of high-level team handball players with a prospective study design. We also wanted to examine injury mechanisms and possible risk factors for ACL injuries, including menstrual status.

Table 1. Competition activity level and number of ACL injuries sustained during official and unofficial games during the 1993–94, 1994–95 and 1995–96 seasons

	ACL iniuries		Player hours*	
	Men	Women	Men	Women
1993–94	0	9	4023	4268
1994–95	3	7	4344	4403
1995–96	0	5	4804	4480
Total	3	21	13171	13151

* Competition exposure has been calculated as the number of matches multiplied by the duration of each match multiplied by 7 players on each team.

Methods

A prospective cohort study of ACL injuries in Norwegian elite team handball was carried out during the 1993–94, 1994–95, and 1995–96 seasons. A total of 24 teams (12 men's and 12 women's teams), all of the teams playing in the elite division of the Norwegian Handball Federation (NHF) league system, agreed to take part in the study. The players on these teams are either amateurs or semi-professionals. The matches were played with equipment and rules in accordance with the regulations of the International Handball Federation (4).

The teams were followed for 12 months each season (June–May). Information about injured players was gathered from team coaches, physiotherapists and physicians, the insurance company, and other team officials. An ACL injury was registered if it occurred during organized handball training or games. All the injured players consented to participate in a personal or telephone interview. Among the information requested in each case was personal data, training history, family history (ACL injury among parents or siblings), menstrual history, and mechanism of injury. The menstrual cycle date was adjusted to an average cycle length of 28 days, with day 1 of the cycle designated as that day on which menstrual flow began. Injuries were classified as occurring in four different menstrual phases (day 1–7: menstrual phase; day 8–14: follicular phase; day 15–21: early luteal phase; day 22–28: late luteal phase). The diagnosis of ACL injury and information on associated ligament injuries, meniscal injuries or osteochondral injuries were obtained from the operating surgeon. The study was approved by the Ethics Committee of the Norwegian Research Council.

The coaches supplied information on the number of official training games, tournament games, and cup and league games each season. Competition exposure for each team was calculated as the number of games multiplied by the duration of each game (some tournament games lasted less than the regulation time of 2×30 min) multiplied by 7 players. Training exposure was calculated based on the average weekly number of training hours reported by the injured players each season multiplied by 48 wks multiplied by 12 players. Injury incidence was calculated as the number of ACL injuries reported per 1000 player hours (competition and/or training, as appropriate).

Statistical methods

Results are given as the mean±SEM unless otherwise noted. Comparisons of activity type (match vs. training), and gender were done using the Mantel-Haenszel test for cohort data with a person-time denominator (5). Comparison of the risk of injury during the four menstrual phases was done using chi-square statistics with three degrees of freedom.

Results

Exposure and injury rate

All the 12 men's and women's teams participating in the elite divisions were followed during the three seasons for a total of 26 321 player hours of game participation (Table 1) and 131 328 player hours of training (62 208 h for women and 69 120 h for men). During this period, there were 28 ACL injuries, 23 among women (incidence: 0.31±0.06 injuries per 1000 player hours) and 5 among men (0.06±0.03 inj./1000 h; $P<0.001$ vs. women; risk ratio: 5.0). Of the 28 injuries, 24 occurred during competition (0.91±0.19 inj./1000 h; women: 1.60±0.35 inj./1000 h; men: 0.23±0.13 inj./1000 h; $P<0.001$ vs. women; risk ratio: 7.0) and 4 during training (0.03±0.02 inj./1000 h;

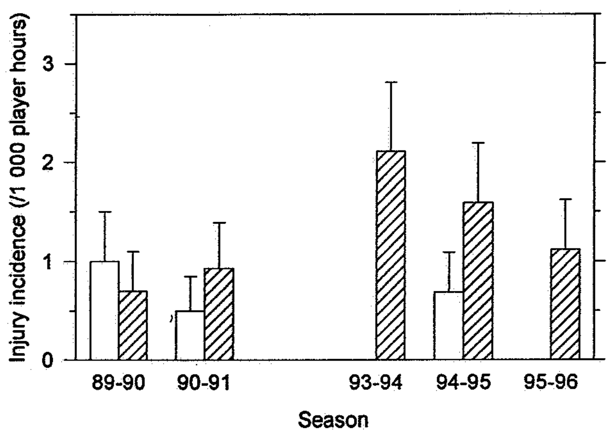

Fig. 1. Yearly rate of ACL injuries during official and unofficial matches in the elite division in Norwegian team handball among male (open bars) and female players (hatched bars). Standard errors are shown with error bars. Data for the 1989–90 and 1990–91 seasons have been estimated from Myklebust et al. (12).

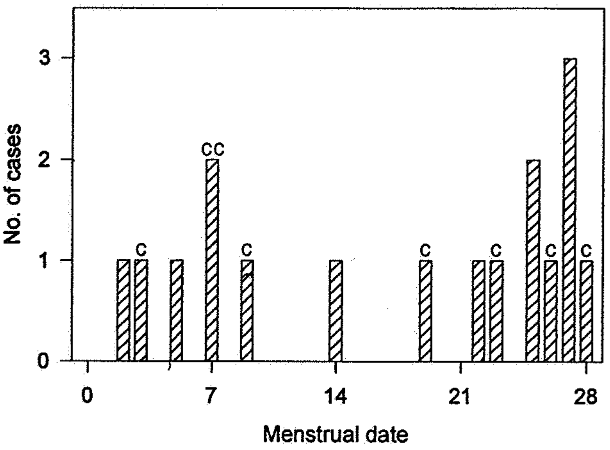

Fig. 2. Distribution of the number of ACL injuries in relation to menstrual date (n=17). C: Contraceptive users.

P<0.001 vs. competition; risk ratio: 29.9). There was no apparent change in ACL injury incidence in the time period from 1989 to 1996 (Fig. 1).

Patient characteristics and risk factors

The age of the injured players was 21.9±3.4 (SD) yrs among women and 23.4±3.9 yrs among men. They started playing handball at age 9.1±2.0 yrs (women) and 8.8±2.3 yrs (men), and had played 3.8±3.5 yrs (women) and 2.4±1.7 yrs (men) in the elite division. They reported practicing for 9.0±2.3 h/wk (women) and 10.0±1.4 h/wk (men). Six of the players reported a family history of ACL injury. Nine of the players had evidence of an associated lateral meniscus injury at surgery, 4 had a medial meniscus injury, and 11 had chondral injuries.

A reliable menstrual history could be obtained in 17 of the 23 cases among females. Of these, 8 used oral contraceptives and 9 had regular menses. Five of the injuries occurred in the menstrual phase, 2 in the follicular phase, 1 in the early luteal phase and 9 in the late luteal phase (chi-square$_{3\ d.f.}$=13.2; P<0.01; Fig. 2).

Injury mechanisms

All but two players were handling the ball when injured; both of these were performing defensive actions (both were non-contact). The other 26 injuries occurred in the attacking phase; only three of these occurred as a contact injury, the other 23 were non-contact injuries, 17 of these when moving at high speed. Of the 23 non-contact injuries, 19 occurred during faking/cutting movements, whereas 4 occurred when landing from a jump. In all but one of the non-contact injuries (male), the player reported that there was nothing unusual with the action performed when injured. Of the non-contact injuries, 18 players reported that the foot was firmly fixed to the floor at the time of injury, in 10 cases with a rotation causing the tibia to be externally rotated in relation to the femur and in 7 cases with internal rotation of the tibia. One player reported a valgus stress and six were not sure.

Discussion

The main observations of this study were that the incidence of ACL injuries was 5-fold higher among women than among men and 30-fold higher during competition than during training. We also found that most of the injuries occurred in non-contact situations when the players performed high-speed plant-and-cut movements which they were well accustomed to. Many of the women sustained ACL injuries during the weeks prior to or after the onset of menses.

Rate of ACL injury

In any epidemiological study the reliability of the injury and exposure registration must be questioned. The present study was done using a prospective study design, where the teams were requested to report any knee injury as soon as they occurred. In addition, the investigators remained in close contact with the team coaches and medical staff throughout the study period. Also, the players were covered by the compulsory injury insurance policy of the NHF and all insurance claims were examined for additional ACL injuries. Even so, there is always a possibility that an injury may have been overlooked. However, an ACL injury usually causes pain, swelling and disability, and it is unlikely that a player may have developed an injury without the need for medical follow-up. Moreover, all the reported ACL injuries were later verified arthroscopically and reconstructive surgery was perfomed. It is therefore highly unlikely that there may have been 'false positive' ACL injuries during the study period.

With respect to exposure registration, it was not possible to base this on attendance records for all practices and matches during the study period. Data on the number of matches were obtained from the coaches, including out-of-season tournaments and training matches, which should ensure good reliability. The training data are less accurate, since these are based on the average number of training hours per week reported by the injured players and coaches. We have assumed that each team consisted of 12 players during training, so the exposure registration has not been adjusted for training attendance or seasonal variations. However, team rosters usually include 14–16 players, which means that we have assumed that some players were absent for various reasons.

Thus, we believe that the injury rates found, 0.31

ACL injuries per 1000 hours among women and 0.06 among men, and the 5-fold gender difference observed are reliable estimates. Arent & Dick estimated injury rates of 0.31 and 0.13 ACL injuries per 1000 exposures in soccer and 0.29 and 0.07 in basketball among women and men, respectively (2). Although the methods and units for exposure reporting are somewhat different, both studies show a marked gender difference.

There were no injuries among goalkeepers. Even so, we have included them in the injury incidence calculations. This has been done to allow for comparison with results from other studies and across different sports. To calculate the injury incidence among court players, one would simply have to multiply the present results by 7/6, i.e. a 17% increase.

Possible mechanisms for ACL injury

The mechanism for ACL injury, and in some cases also rupture of the medial collateral ligament and medial meniscus, is the forceful valgus-external rotation of the knee which can occur in skiing injuries, where the tip of the ski is caught in the snow or by an obstacle (6, 7). Other forced injury mechanisms have also been described (8, 9): Internal rotation-hyperextension, hyperflexion, backward fall ('boot-induced anterior drawer', seen in downhill skiing). However, recent studies have shown that ACL injuries can occur in team sports such as basketball (2, 10, 11) and team handball (12, 13). In a previous study from team handball we have shown that 95% of the ACL injuries were non-contact (12), and in the present study 89% of the injuries occurred without player contact.

The exact injury mechanism in these cases is not clear. It is noteworthy that of the 23 non-contact attack injuries observed in the present study, 19 occurred during plant-and-cut maneuvers, and in all but one of these the players reported that there was nothing unusual about the faking movement performed. In other words, the ACL 'popped' when the players were performing fakes that they had done hundreds or thousands of times before, as can be seen by the fact that the injured players were very experienced (at least 4 yrs at the elite level).

With respect to knee position at the time of injury, the information is less clear, some reporting external rotation of the tibia and some reporting internal rotation, but nearly all reported that their foot was planted on the floor at the time of injury. We were not able to gather reliable information on valgus-varus stresses on the joint.

Gender differences in ACL injury rates

Several different hypotheses have been suggested to explain the marked gender difference in ACL injury rates, e.g. differences in lower extremity alignment (1, 14), notch dimensions (15, 16), ligament size (1), muscle strength and coordination (17, 18), and level of skill and conditioning (1, 2). It has also been suggested that there may be sex differences in ligamentous laxity, possibly related to cyclic hormonal effects (1), but there are no studies supporting this hypothesis. In this study, most of the injuries occurred during the weeks prior to or after the start of the menstrual period. This corresponds with the findings of Møller-Nielsen & Hammer (3), who observed an increase of traumatic injuries in general during the premenstrual and menstrual phases in female soccer players. In their study, players with premenstrual problems, such as irritability or swelling/discomfort of the breasts, were at greater risk of injury. In the present study we have no information about these factors. They also observed that women using oral contraceptives had a lower injury rate than those who did not.

The observation of an apparent relationship between menstrual phase and ACL injury risk must be interpreted with caution, since it is based on a small number of observations. Also, the players were not followed with a continuous record of menstrual status throughout the study period, and in some cases a reliable menstrual history could not be obtained. Further studies are therefore necessary to examine this relationship, but it is conceivable that the normal hormonal fluctuations during the menstrual cycle may have effects on ligamentous tissue. Liu et al. have recently demonstrated the presence of both estrogen and progesterone receptors in synoviocytes in the synovial lining and in fibroblasts in the stroma in human ACL specimens, suggesting that female sex hormones may have an effect on the structure and composition of the ligament (19). Increased joint laxity has been suggested as a possible factor for the increased injury incidence among women (1, 2), but the effects of female sex hormones on the material properties of ligaments have not yet been examined.

Conclusion

The incidence of ACL injuries was 5-fold higher among women than men and 30-fold higher during competition than training. Nearly all the injuries occurred in non-contact situations when the players performed high-speed plant-and-cut movements which they were well accustomed to. The results also suggest that there may be an increased risk of ACL injury during the week prior to or after the start of the menstrual period.

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Paper III

Clinical, functional and radiological outcome 6-11 years after ACL injuries in team handball players – a follow-up study

[1]Grethe Myklebust, [2]Inger Holm, [3]Sverre Mæhlum, [1,4]Lars Engebretsen, [1]Roald Bahr

[1]Oslo Sport Trauma Research Center, University of Sport and Physical Education, [2]National Hospital, [3]Norwegian Institute of Sports Medicine, [4]Oslo Orthopedic University Clinic, Oslo, Norway

Running title: Long-term outcome after ACL injury

Address correspondence and reprint requests to Grethe Myklebust at: Oslo Sport Trauma Research Center, University of Sport and Physical Education, 0806 Oslo, Norway. Telephone: +47 23262370-Fax: +47 23262307-E-mail: grethem@nih.no

Abstract

An eight-year follow-up study was carried out in order to evaluate the outcome after ACL injury in team handball players. All the players who suffered an ACL rupture in the top three divisions during the 1989-91 seasons (n=87; 54 females, 33 males) were invited to participate in the following examinations after 7.8 (6-11) years: questionnaire-based interview (n=79), clinical examination and KT-1000 (n=71), IKDC evaluation (n=70), functional tests and Lysholm score (n=69), strength tests (n=63), and a radiological examination (n=50). Fifty-seven players were treated operatively and 22 non-operatively. In the operatively treated group 33 (58%) returned to team handball at their pre-injury level, compared with 18 (82%) in the non-operatively treated group. Eleven (22%) of the 50 players who continued playing re-injured their ACL – all when playing team handball. The overall Lysholm score was 85±13, and there was no difference between the treatment groups. The five players classified as poor were all in the operatively treated group. Nearly half of the players were classified as abnormal/severely abnormal in the IKDC evaluation system. We found statistically significant differences between the injured and uninjured leg in functional tests (2.5-8%), strength tests (3.8-10.1%) and KT-1000 (27%). In the operatively treated group 11 (42%) had developed radiological gonarthrosis, compared with 6 (46%) in the non-operatively treated group. There was no correlation between radiological findings and pain scores. These results, particularly the high re-rupture rate, indicate that a more restrictive attitude on the return to competitive pivoting sports may be warranted.

Key words

ACL injury, follow-up study, knee function, graft rupture, return to sport, activity level, European team handball.

Structured abstract

Background: The long-term outcome after an ACL injury among top level pivoting athletes is unknown.

Aims: To evaluate the outcome 6-11 years after ACL injury in a cohort of competitive team handball players, including the return rate to sport at pre-injury level and the re-injury rate after reconstruction. We also wanted to examine the prevalence of radiological changes and their relationship to the clinical outcome.

Study design: Prospective cohort follow-up study.

Methods: All the players who suffered an ACL rupture in the top three divisions during the 1989-91 seasons (n=87) were invited to participate in the following after 7.8 (6-11) years: questionnaire-based interview (n=79), clinical and KT-1000 examination (n=71), IKDC evaluation (n=70), functional tests and Lysholm score (n=69), strength tests (n=63), and a radiological examination (n=50).

Results: Fifty-seven players were treated operatively and 22 non-operatively. In the operatively treated group 33 (58%) returned to team handball at their pre-injury level, compared with 18 (82%) in the non-operatively treated group. Eleven (22%) of the 50 players who continued playing re-injured their ACL – all when playing team handball. The overall Lysholm score was 85±13, and there was no difference between the treatment groups. The five players classified as poor were all in the operatively treated group. Nearly half of the players were classified as abnormal/severely abnormal in the IKDC evaluation system. We found statistically significant differences between the injured and uninjured leg in functional tests (2.5-8%), strength tests (3.8-10.1%) and KT-1000 (27%). In the operatively treated group 11

(42%) had developed radiological gonarthrosis, compared with 6 (46%) in the non-operatively treated group. There was no correlation between radiological findings and pain scores.

Conclusion: The return rate to sport to pre-injury levels was high, whether treated operatively (59%) or not (82%), but the re-injury rate in the operatively treated group was high (22%). Also, about half of the players in both groups complained of pain, instability or reduced range of motion 6-11 years after their ACL injury, and nearly half of the players had signs of osteoarthritis – although there was no relationship between radiological status and pain scores.

Clinical relevance: The results, indicate that a more restrictive attitude on the return to competitive pivoting sports may be warranted.

Introduction

A high incidence of anterior cruciate ligament (ACL) injuries has been reported in team handball, as well as in other team sports, such as basketball, volleyball and soccer [8 9 15 19 20 46 26 27]. The treatment of ACL injuries has improved during the last 10-15 years, at least such that many patients are able to return to high-level sports. It seems generally accepted that the preferred treatment for patients in pivoting and high-speed sports is a delayed reconstruction of the ACL using a patellar tendon or hamstrings graft [23].

Although advances in surgical methods have been made, exact information on the return rate to pre-injury sporting level after an ACL injury is limited. Daniel demonstrated in a prospective outcome study that almost half of the patients, whether conservatively treated or operatively treated, continued with sports like basketball, soccer, racket sports or skiing [6]. Roos examined soccer players with an ACL injury, representing all levels of competition, three and seven years after their injury. He found that only 30% of the players were active in soccer three years after injury compared with 80% in an uninjured control population. After seven years none of the injured elite players were active at the same level, independent of whether the patient were treated operatively or conservatively after the injury [37]. Strand and Solheim showed that only 1/3 of team handball and soccer players had returned to their pre-injury level two years after their ACL reconstruction [45]. Scavenius found in a study on conservatively treated patients seven years after the ACL injury that only two of 24 players returned to be cutting sports performers [39]. However, the available studies have examined mixed groups of patients from different sports and mainly lower performance levels. No data is available on the return rate among elite athletes in a pivoting sport like team handball after an ACL injury.

Moreover, few studies report on the re-injury risk after ACL reconstruction. Mitsou and Vallianatos reported only one graft rupture in a five to nine-year follow-up study on 334 athletes after a reconstruction using the lateral third of the patellar tendon, but their sports activities after reconstruction were not reported [25]. Sandberg and Balkfors did a five-year follow-up of 112 patients treated with a reconstruction of the ACL using the middle third of the patellar tendon, and they found that 11 (10%) reconstructions had ruptured, eight of them during sports activity [38]. Otto et al found in a five-year follow-up of patients with reconstructed patellar tendon autografts that only three of 80 (4%) re-ruptured their ACL, two of them in pivoting sports [33]. Bak et al studied 132 soccer players with an iliotibial band reconstruction, and found a higher re-rupture rate among female than male players. Three of 15 female players (20%), compared with only one of 117 males (0.3%) re-ruptured their reconstructed knee [3]. However, all of these studies were based on mixed patient populations of non-athletes and athletes from different sports and performance levels. The re-rupture rate among elite athletes in knee-demanding sports is unknown.

One potential long-term problem after an ACL injury, whether the treatment is operative or non-operative, is osteoarthritis to the knee. In a review Gillquist and Messner [11] concluded that the prevalence of radiographic gonarthrosis is increased after all types of knee injuries compared with the uninjured joint of the same patient. A total rupture of the ACL seems to increase the risk ten-fold compared with an age-matched uninjured population. This serious consequence occurs despite the ability to rectify the instability surgically. We still lack evidence to suggest that ACL reconstruction decreases the rate of post-traumatic osteoarthritis in the knee [21]. In fact, it may even be hypothesized that an effective ACL reconstruction increases the risk of future osteoarthritis by enabling the athlete to return to high-performance pivoting sports – either through re-injury or due to the high demands put on the knee.

In other words, so far there are no studies on a homogeneous group of competitive pivoting-sport athletes examining the short- (i.e. return to sport) or long-term consequences (i.e. knee function, radiographic evidence of osteoarthritis and how the patients cope in sport and with activities of daily living) after an ACL injury.

Thus, the aims of this study were to evaluate the return rate to sport at pre-injury level, the re-injury rate after reconstruction, and clinical outcome 6-11 years after an ACL injury in a cohort of competitive team handball players. We also wanted to examine the prevalence of radiological changes and their relationship to the clinical outcome.

Material and methods

The present study was based on a patient population from a previous study [26]. In this study all ACL injuries in the three upper divisions in Norwegian team handball were recorded prospectively during the 1989–90 and 1990-91 seasons, and a total of 87 ACL injuries were found. One of the original 87 patients recorded was later found to have a posterior cruciate ligament injury. The remaining 86 (53 women and 33 men) were invited to take part, and 79 patients (91%) responded to a questionnaire 7.1 (6-8) years after injury. Of the remaining, four patients were not available for follow-up due to emigration and three patients declined to take part in the study.

The Data Inspectorate and the Regional Ethical Committee for Medical Research approved the study, and the players gave their written consent to participate after receiving information about the purpose and procedures of the study.

In addition to the questionnaire they were asked to participate in a clinical examination, IKDC evaluation and Lysholm score, functional tests, a KT-1000 arthrometer examination, strength tests, and a radiological examination. Also, their hospital records were obtained to confirm the diagnosis and classify the operation type where a surgical reconstruction had been done. The initial diagnosis was confirmed with arthroscopy in 64 cases and clinical examination in 15 cases. None of the authors had done the surgical procedures in the study.

Seventy-one players (46 women and 25 men) went through a clinical examination and KT-1000 arthrometer examination, IKDC evaluation (n=70), functional tests and Lysholm score (n=69), strength test (n=63), and finally a radiological examination (n=50) 9.4 (7-11) years after injury.

Questionnaire

The players were interviewed in person or by telephone using a standardized questionnaire. Among the information requested was personal data, rehabilitation and recovery history, return to sport, history of knee problems after the ACL injury, and any consequences the injury may have had for activities of daily living.

Clinical examination

A clinical examination of both knees was carried out by two experienced physicians. Range of motion was measured by goniometer and thigh circumference was measured 5 and 10 cm from the top of the patella. Patellofemoral pain and crepitation was graded as 0 (absent), 1+ (mild), 2+ (moderate) and 3+ (severe). Lachman, anterior drawer, pivot shift, medial and lateral joint opening (in 0° and 30° flexion) tests were performed. Anterior laxity was graded as 1+ (0 to 5 mm), 2+ (6 to10 mm), or 3+ (>10 mm).

KT-1000 arthrometer testing

The KT-1000 arthrometer examination (MEDmetric, San Diego, California, USA) was done by the same experienced physical therapist as described by Daniel et al. using the 134 N and manual maximal tests [7]. A side-to-side difference of 3 mm or more was defined as abnormal.

Muscle performance test

Isokinetic equipment (Cybex 6000 dynamometer, Cybex-Lumex Inc, Ronkonkoma, New York, USA, or Biodex System 2 Isokinetic Dynamometer, Biodex Medical Inc., Shirley, NY, USA) was used to evaluate quadriceps and hamstrings performance. All the tests were performed by the same experienced physical therapist. Prior to testing the players warmed up on a cycle ergometer for eight minutes. They were then fixed to the apparatus with straps securing the chest, pelvis, thigh and ankle [16]. Both limbs were tested, the uninvolved side first. The protocol consisted of five repetitions at an angular velocity of 60 °/s, followed by a one-minute rest period and 30 repetitions at 240 °/s. The results were reported as the mean value of total work at both angular velocities.

Functional testing

The players performed a single jump test, a triple jump test and the stair hopple test [36]. The single jump test was performed with the player jumping and landing on the same leg, uninvolved side first. The triple jump test was performed with the player first standing on the uninjured leg, jumping twice on the same leg and landing on both legs. The same procedure was used for the involved leg. Two trials were done on each leg and the best performance was recorded. In the stair hopple test the player were timed jumping up and down 22 steps (each step 17.5 cm high), first on the uninvolved side, subsequently on the involved side, one trial on each leg.

IKDC and Lysholm evaluation forms

The International Knee Documentation Committee (IKDC) [13] and Lysholm [22] rating scales were used to evaluate knee function. Both scales were assessed by the physician in the course of the patient examination.

The IKDC evaluation form consists of eight variables: patient subjective assessment (IKDC 1), symptoms (IKDC 2), range of motion (IKDC 3), ligament examination (IKDC 4), compartmental findings (patellofemoral crepitus), harvest site pathology, X-ray findings, and the one-leg-hop test. Only the first four variables (IKDC 1-4) are graded, as: normal (1), nearly normal (2), abnormal (3), or severely abnormal (4). The worst subgroup evaluation determines the group qualification and the worst group qualification determines the final evaluation. In this study the IKDC 1-4 and the IKDC final scores were evaluated. Data on compartmental findings was not collected. The results from the radiographic evaluation, harvest site pathology and functional tests are not included in the IKDC final score, and have been reported separately.

The Lysholm score consists of eight items, where instability and pain account for 25 points each out of the total score of 100 points. In this scale 95-100 points is considered as excellent, 84-94 good, 65-83 fair, and 64 and below as poor [22].

Radiographic assessment

The radiographic evaluation included a standing frontal radiograph. Gonarthrosis was defined as joint space narrowing with a loss of distance between the tibia and the femur in one compartment of half or more of the distance in the other compartment of the same knee joint, or the same compartment of the other knee, or less than 3 mm [1]. An experienced orthopedic surgeon, blinded to the clinical outcome, assessed the radiographs.

Statistical methods

The descriptive data are presented as the arithmetic mean, standard deviation (SD) and/or range, unless otherwise noted. Paired t-tests were used to compare the involved and uninvolved legs. Unpaired t-tests were used to compare group means. For nominal categorical data a chi-square test was used to determine whether there were significant differences between groups. Mann Whitney test were used for ordinal categorical data. One-way ANOVA was used to test mean differences between different treatments. An alpha level of 0.05 was considered as statistically significant.

Results

Treatment

Of the 79 players (50 female and 29 male) interviewed, 57 (72%; 37 women and 20 men) were treated operatively and 22 (28%; 13 women and nine men) were treated without surgery. From the hospital records we found that 47 players (82%) in the operative group had a bone-patellar tendon-bone graft reconstruction, in eight cases (14%) a suture was done, and two players (4%) had an unknown procedure. The players in the operative groups had gone through 1.7 surgical procedures (1-8) from the time of injury to the follow-up.

Return to sport

In the non-operatively treated group 18 players (82%; 11 women and seven men) returned to team handball at the same level as before the injury occurred. Two players continued playing on a lower level, and two players had never played team handball after the injury. In the operatively treated group 33 players (58%; 20 women and 13 men) continued playing at the same level, 17 (30%) at a lower level, while seven had never played again. The players in the non-operative group continued playing at the same level for 4.1 (1-10) years, compared with 3.8 (1-7) years in the operative group.

Re-injury risk

Of the 50 players in the operative group who continued playing team handball 11 (22%) re-injured their ACL, all when playing team handball (*Figure 1*). Of the 11 re-injuries, five had BPTB grafts, four primary repairs and two "other" techniques. Eight of the re-injured players were re-operated, all of them with a bone-patellar tendon-bone graft procedure. Two of them re-ruptured their ACL for the second time while playing team handball. Six of the players (9%) who continued playing team handball ruptured the ACL on the uninjured side. There were no re-injuries among the seven players with BPTB graft who quit playing team handball.

Figure 1 near here

Types of problems

The main problems in the non-operative group were instability (62%) and joint effusion (24%), while the operative group reported problems with reduced range of motion (43%), instability (25%), reduced muscle strength (24%), and joint effusion (24%).

Knee problems had forced 12 (57%) in the non-operative group and 26 (45%) in the operative group to reduce or quit leisure and sports activities. Five (24%) in the non-operative group and 15 (26%) in the operative group reported work-related problems caused by their knee.

Twenty-nine (51%) of the players in the operative group reported having patellofemoral pain, and 16 (28%) of them were tender to palpation of the distal patellar pole. In the non-operative group three patients reported having patellofemoral pain (14%).

Lysholm score

The Lysholm score was 85±13 (n=69). Based on their Lysholm score, 19 patients (28%) were classified as excellent, 30 as good (43%), 15 as fair (22%) and five as poor (7%). The five patients who were classified as poor were all in the operative group, four with a bone-patellar tendon-bone graft procedure and one with a suture. *Figure 2* shows Lysholm scores for women and men in the different treatment groups. There was no difference between the three treatment groups (ANOVA, p=0.3).

Figure 2 near here

IKDC evaluation score

Using the IKDC evaluation system (n=70), nine players (13%) were classified as normal, 31 (44%) as nearly normal, 21 (30%) as abnormal, and nine (13%) as severely abnormal (*Figure 3*). The nine players who where classified as severely abnormal were all in the reconstructed groups. Five of them received their abnormal score from IKDC 1 (patient's subjective assessment) and four from the IKDC 2 (symptoms).

Figure 3 near here

Functional tests

Performance was reduced in the involved compared with the uninvolved side for the one-leg jump (p=0.006), triple jump (p=0.003), and stair hopple tests (p=0.018) (*Table 1*). There was no difference between the treatment groups in the triple jump test (ANOVA, p= 0.92), one-leg jump test (p= 0.57), or stair hopple test (p= 0.66).

Table 1 near here

Muscle strength tests

Performance was reduced in the involved compared with the uninvolved side, for total work during flexion at 60°/s (p=0.038), flexion at 240°/s (p=0.03), extension at 60°/s (p=0.000), and extension at 240°/s (p=0.000) (*Table 2*). There was no difference in the involved-uninvolved leg difference for total work during flexion at 60°/s

(ANOVA p= 0.15), flexion at 240°/s (p=0.30), extension at 60°/s (p= 0.94), or extension at 240°/s (p=0.46) between the treatment groups.

Table 2 near here

Knee stability (KT-1000 arthrometer testing)

All treatment groups showed an increased anterior displacement when comparing the involved with the uninvolved leg (*Table 3*). In the group treated with a bone-patellar tendon–bone graft procedure, 26 patients of 42 (62%) showed a side-to-side difference of <3 mm in anterior displacement, while nine patients (22%) displayed a difference of 3-5 mm and 11 patients (26%) had >5 mm difference. Among the patients treated with other procedures and non-operatively treated patients, the corresponding figures were seven (<3 mm; 58%), one (3-5 mm; 8%), four (>5 mm; 33%) and seven (<3 mm; 41%), two (3-5 mm; 12%), eight (>5 mm; 47%), respectively. There were no differences in the 30 Ibs test (ANOVA, p=0.20) or manual maximal test (p=0.44) between the different treatment groups.

Table 3 near here

Thigh circumference

In the operatively treated groups, 37 players (64%) had full quadriceps muscle bulk or less than one cm difference between the two limbs, while 16 players (28%) had a one to two cm difference, four players (7%) a two to three cm difference, and one player more than a three cm difference. In the non-operatively treated group 19 players

(90%) had less than one cm thigh difference, and two players (10%) had a one to two cm difference.

Radiological findings

Radiographs were obtained from 13 players from the non-operatively treated group and 37 players from the operatively treated groups. In the non-operatively treated group six of the players (46%) had developed gonarthrosis, while the corresponding number for the reconstructed group was 11 (42%). The Lysholm pain score was 18±2 (n=16) among players with radiological gonarthrosis and 19±1 (n=32) among players without radiological changes ($p=0.79$, unpaired t-test).

There was no correlation between the radiological findings and IKDC pain score ($p= 0.27$; Mann Whitney non-parametric test accounting for tied observations) (*Table 4*).

Table 4 near here

Discussion

The principal findings of this study were that the return rate to sport to pre-injury levels was high, whether treated operatively (59%) or not (82%), but the re-injury rate in the operatively treated group was high (22%). Also, about half of the players in both groups complained of pain, instability or reduced range of motion 6-11 years after their ACL injury, and nearly half of the players had signs of osteoarthritis – although there was no relationship between radiological status and pain scores.

A follow-up study like the present has some limitations that must be borne in mind when interpreting the results. The two groups in this study, the operatively and non-operatively treated patients, are in nature difficult to compare since the reasons why they were treated as they were are unknown. A selection bias could exist, e.g. that the reconstructed patients may have had a more unstable knee, and therefore selected surgery. The non-operatively treated patients may have chosen non-operative treatment in consultation with their physicians because they had a functionally stable knee, because they wanted to return to team handball at the same level more quickly, or a strong motivation to rehabilitate without surgery. They may also have been more willing to tolerate giving-way episodes to achieve their goal. All these are factors that suggest that the operatively and non-operatively treated groups should be compared only with caution. Also, there may have been similar differences between the patients who returned to elite sport and those who did not. Thus, the primary purpose of the study was not to compare non-operative with operative treatment or return to sport with retirement from sport, but simply to describe the long-term results in each of these subgroups. It should be noted that it is not possible to conduct a prospective study where patients are randomized to elite level sport and retirement, or even surgery and non-operative treatment. Therefore, the only way to examine the long-term consequences of return to top-level pivoting sports is a follow-up study like the present.

The strength of the present study is that the injured players have been followed from the time of injury to the follow-up with a high response rate. To our knowledge, it is the first prospective long-term follow-up reported on a homogenous group of high-level athletes from a pivoting sport.

Return rate to sport

Previous studies have reported a low return rate to cutting sports after conservative treatment of ACL injury [10 8;28;39]. Bjordal concluded that reconstructive surgery was necessary to be able to play soccer again [4]. This in contrast to the present study – where 82% of the conservatively treated patients returned to competitive team handball at their pre-injury level of performance. The reason for this apparent inconsistency may be that the non-operatively treated group is a selected subgroup of patients with functionally stable knees, but it should be noted that the patients who returned to sports without surgery comprise as much as one fourth of the entire cohort of injured players. Roos et al. reported in a study of ACL injured soccer players that only 30% of the players were active soccer players after seven years, and the ability to return to soccer was the same regardless of treatment choice [37]. One explanation of the high return rate in our cohort may be high motivation and strong wish to play team handball again, despite the fact that many players had problems with pain, instability or reduced range of motion.

Re-injury risk

The high re-injury rate in our study (11 out of 50 players who returned to team handball; 22 %) is surprising compared with other studies [25 38 33 3]. One reason for the high re-rupture risk seen in the present study could be the fact that many of the players returned to team handball, which in itself is a high-risk sport [26 27]. This is reflected by the fact that six of the 50 players who returned to team handball (9 %) experienced an ACL tear in their uninvolved, previously uninjured knee during the study period. In other studies where the number of re-ruptures has been reported, Sandberg and Balkfors observed the highest rate in patients reconstructed with the middle third of the patellar tendon with 10% [38].

The choice of reconstructive technique is of great importance for the re-rupture risk. It is not surprising that four of the eight knees where a simple suture was done failed.

Previous studies have shown that a suture of the ACL has a greater failure rate than bone-patellar tendon-bone autograft [12 43]. Nevertheless, it should be noted that 5 of 40 patellar tendon grafts (13%) also failed, plus two reruptures among the eight players who underwent a second surgical procedure. It may be argued that surgery has been done in several hospitals by many different surgeons, and that the results may be a reflection of variable surgical skills. For instance, although we were unable to evaluate tunnel placement, it is possible that a fair number of patients may have had improperly placed femoral or tibial tunnels based on the techniques used then. On the other hand, the results reflect the outcome of ACL reconstruction when employed on a large scale.

Moreover, not only the surgical technique chosen, but also the quality of the post-operative rehabilitation programs may influence the failure rate. We have not examined the rehabilitation protocols the players have gone through, but since six months of rehabilitation with physical therapists is provided at no cost, most of them have probably followed a training program. During the late 80s and early 90s the rehabilitation programs included early full extension after surgery and mainly consisted of strength-based exercises with a combination of closed and open kinetic chain exercises. Recent data suggests that neuromuscular training may prevent ACL injuries [5], and it may be that strength-based rehabilitation programs alone are inadequate to protect against re-injury [14 48]. Another explanation for the high re-rupture risk could be that these players simply represent a high-risk population, characterized by anatomical, hormonal or other risk factors yet to be identified [2].

Knee stability

The majority of the players (63%) had an a-p laxity over three mm, which is defined as pathological knee instability, and for the reconstructed group these results are failures according to universal failure definitions [3]. Still, many of them played team handball. In a comparative study of two techniques for ACL reconstruction O'Neill found two patients with seven and nine mm side-to-side difference in knee laxity, and both participated in sports with a perfect Lysholm score [32]. One reason for the high proportion of players with instability could be that they had stretched their ACL while continuing to play team handball, although they may have been initially stable or stabilized through reconstruction. Another reason could be that the players – particularly the non-operative group – were functionally stable despite having an increased a-p-laxity initially. This has been reported by Snyder-Mackler et al. in a study of anterior displacement in two groups of conservatively treated ACL patients [42]. One of the groups returned to high level sports activity, the other was not able to continue sport. They found no differences in anterior displacement between the groups. They concluded that there was no correlation between a-p instability and function [42]. A-p laxity is not a good test for functional stability, since it does not take into account muscle strength and neuromuscular ability, and knee laxity tests should be dynamic rather than static [47].

Knee function

Whether the players were treated operatively or non-operatively, we found reduced performance in the functional tests and reduced muscle strength in the involved leg compared with the uninvolved leg. The side-to-side differences were moderate (3.8-10.1%), and the clinical significance and influence on knee function during activities of daily life or sports activity is unknown. Several investigators have reported that reduced muscle strength correlates moderately with functional knee tests [49 34 35]. However, players with reduced hamstrings strength could have a reduced ability to stabilize the knee, resulting in an increased re-injury risk [17 41].

Based on the Lysholm score 28% of the patients reported a fair or poor result, whereas 43% of the patients where classified as abnormal or severely abnormal based on the IKDC evaluation scores. The IKDC is a good method to record a clinical examination at one follow-up, and although it has limited value when examining clinical changes over time [35] it showed that [18] almost half of the patients had significant problems with their knee at follow-up.

Radiological findings

Studies have shown that an ACL rupture – alone or in combination with meniscal or collateral ligament injury – results in osteoarthritic changes in 60 to 90% of patients ten to 20 years after the injury [29 30 40]. After conservative treatment of ACL injuries there is a high risk of developing osteoarthritis [44 24], but one study [31] even showed a lower rate of osteoarthritis in conservatively treated patients 20 years after injury compared to those with reconstructed knees. Another study showed only 1% osteoarthritis in patients who had undergone ACL reconstructions five to nine years ago [25]. In our study approximately half of the examined players in both the conservatively and reconstructed groups had developed radiological signs of osteoarthrosis. These results are not surprising, considering that so many of the players returned to the high loads and pivoting characteristic of team handball. It should be noted that since Rosenberg, skyline or lateral views not were available, and patellofemoral arthrosis could not be evaluated, our results represent a minimum estimate of the prevalence of radiographic osteoarthrosis.

Since only 50 of the 78 players recruited for the follow-up study underwent the radiological examination a selection bias may exist. However, based on the results from the IKDC and Lysholm evaluations it does not appear that there was a disproportional recruitment of players with more knee problems. A more reasonable explanation for the lower response rate for the radiological examination could be that some players had to travel a considerable distance to get radiographs taken.

Implications

Otto has recently stated that once knee stability has been achieved, the next objective is to return patients to their pre-injury levels of activity [33]. This statement probably reflects the treatment goal of most surgeons and therapists working with ACL-injured athletes, as well as the expectations of the injured athletes themselves. Based on the present data it seems reasonable to question whether return to high-level pivoting sports really is in the player's interest – if long-term knee health is the primary concern. In the present study, knee function was compromised in about half of the players 6-11 years after an ACL injury, whether they had surgery or were treated non-operatively. We readily acknowledge that we do not know what the outcome would have been if the players in the operatively or non-operatively treated groups had not returned to team handball. We also do not know whether the disability was caused by the initial injury, was a result of re-injury or due to the high-load repetitive twisting strain associated with high-level play, but we do know that re-ruptures occurred only in the players who returned to sport. Finally, we do not know whether the surgical procedures were acceptable compared with contemporary standards. Nevertheless, our results suggests to us that recommendations concerning return to high-level pivoting sports after an ACL injury should be restrictive, if long-term knee function is the primary objective. We recognize that this is not the currently prevailing opinion in sports medicine, and that our findings will need to be borne out by additional studies in other elite athletic populations.

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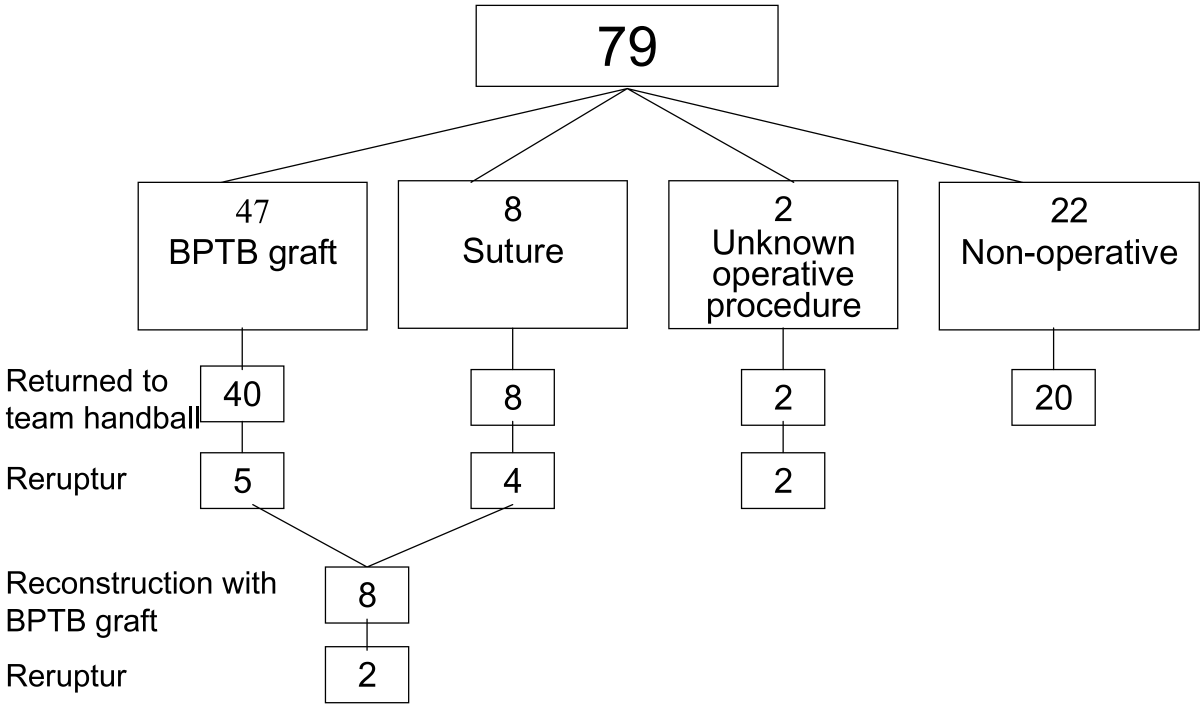

Figure 1. Flowchart depicting treatment history, return to sport and the number of re-ruptures

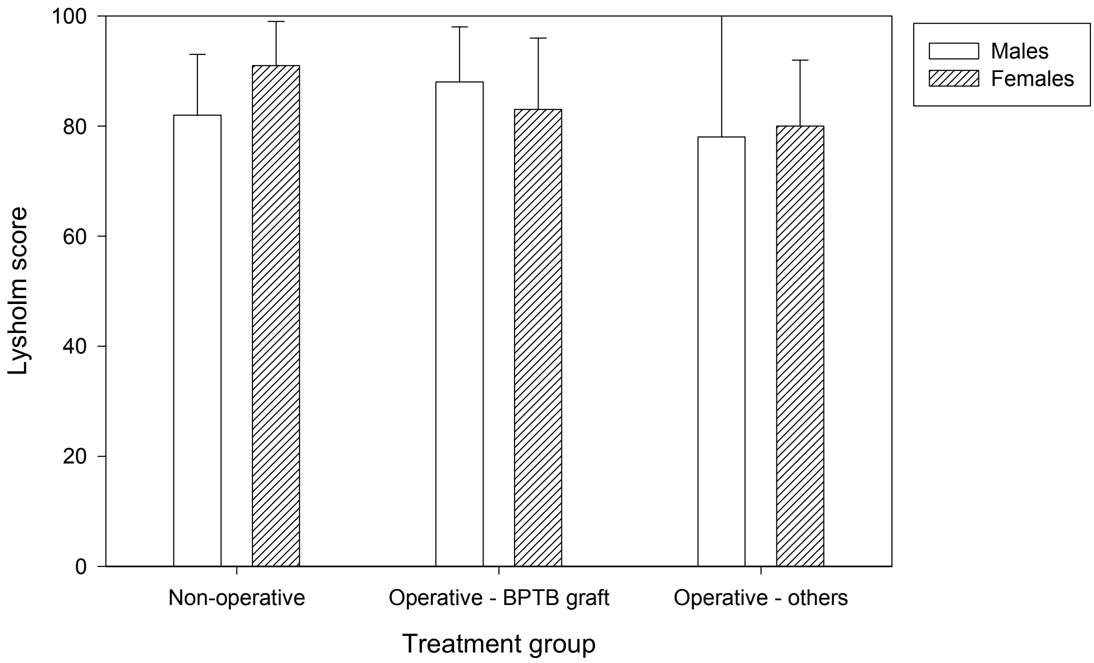

Figure 2. Lysholm score ±SD for both genders and for the three treatment groups; patients treated non-operatively, with a bone-patellar tendon-bone (BPTB) graft, or with other operative procedures.

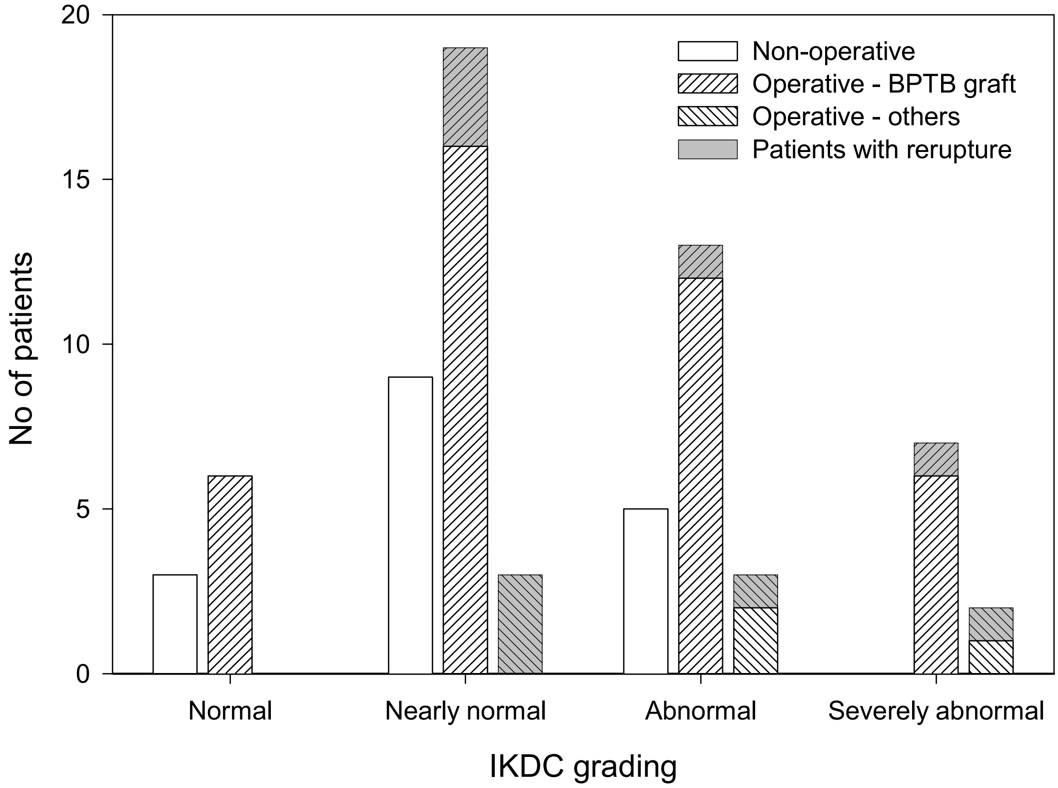

Figure 3. Overall IKDC assessment results (n=70) for the three treatment groups; patients treated non-operatively, with a bone-patellar tendon-bone (BPTB) graft, or with other operative procedures. Patients with re-ruptures in each group are shown with shaded bars.

Table 1. Triple jump, one-leg jump and stair hopple test differences between involved and uninvolved leg for the whole group as well as for the three treatment groups; patients treated non-operatively, with a bone-patellar tendon-bone (BPTB) graft, or with other operative procedures. Results are shown as mean or mean side-to-side differences ±standard error. Comparisons between the involved and the uninvolved leg were done using paired t-tests: * p<0.05, ** p< 0.01, and *** p< 0.001.

Test	All patients			Non-operative	BPTB graft	Other operative
	Uninvolved	Involved	Difference			
Triple jump (cm)	**527±10 (n=69)	514±10 (n=69)	13±4.3 (2.5%)	11±8 (2.2%) (n=17)	*15±5(2.4%) (n=41)	10±13 (2.2%) (n=11)
One-leg jump (cm)	**156±3.3 (n=68)	150±3.6 (n=68)	6±1.9 (8%)	2±3 (0.7%) (n=17)	*7±3 (4.4%) (n=41)	7±7 (3.3%) (n=10)
Stair hopple test (s)	*29±1.2 (n=58)	31±1.4 (n=58)	2±0.8 (6.9%)	2±1 (2.9%) (n=17)	1±1 (3.6%) (n=32)	3±2 (12.5%) (n=9)

Table 2. Flexion total work 60°/s, flexion total work 240°/s, extension total work 60°/s and extension total work 240°/s differences between involved and uninvolved leg for the whole group as for the three treatment groups; patients treated non-operatively, with a bone-patellar tendon-bone (BPTB) graft, or with other operative procedures. Results are shown as mean or mean side-to-side differences ±standard error. Comparisons between the involved and the uninvolved leg was done using paired t-tests: * p<0.05, ** p< 0.01, and *** p< 0.001.

Test	All patients			Non-operative	BPTB graft	Other operative
	Uninvolved	Involved	Difference			
Flexion total work (60°/s)	*572±19 (n=63)	550±18 (n=63)	22±10 (3.8%)	34±22 (6.0%) (n=15)	7±13 (1.0%) (n=37)	59±29 (10.2%) (n=11)
Flexion total work (240 °/s)	***1520±64 (n=63)	1376±59 (n=63)	144±31 (9.5%)	**221±71 (14%) (n=15)	**134±40 (8.6%) (n=37)	73±60 (5.4%) (n=11)
Extension total work (60 °/s)	***900±28 (n=63)	809±26 (n=63)	91±18 (10.1%)	***80±19 (8.8%) (n=15)	***93±24 (11.1%) (n=37)	99±64 (10.2%) (n=11)
Extension total work (240 °/s)	***2286±87 (n=63)	2061±77 (n=63)	225±40 (9.8%)	137±83 (6.1%) (n=15)	***257±46 (11.1%) (n=37)	238±125 (10.2%) (n=11)

Table 3. Anterior displacement tests between the involved and the uninvolved leg for the whole group as for the three treatment groups; patients treated non-operatively, with a bone-patellar tendon-bone (BPTB) graft, or with other operative procedures. Results are shown as mean or mean side-to-side difference ±standard error. Comparisons between the involved and the uninvolved leg was done using paired t-tests: * p<0.05, ** p< 0.01, and *** p< 0.001.

Test	All patients			Non-operative	BPTB-graft	Other operative
	Uninvolved	Involved	Difference			
30 Ibs	***9.6±0.4 (n=71)	13.2±0.4 (n=71)	3.6±0.4 (27%) (n=71)	***4.9±0.9 (35%) (n=17)	***3.3±0.4 (26%) (n=42)	*3.1±1.4 (22%) (n=12)
Manual maximal	***10.4±0.3 (n=71)	14.2±0.4 (n=71)	3.9±0.4 (27%) (n=71)	***4.7±0.5 (31%) (n=17)	***3.6±0.4 (26%) (n=42)	*3.7±1.3 (26%) (n=12)

Table 4. IKDC pain score results related to radiological findings.

Arthrosis	N	Normal	Nearly normal	Abnormal	Severely abnormal
Yes	15	9 (60%)	2 (13%)	1 (7%)	3 (20%)
No	29	21 (72%)	5 (17%)	2 (7%)	1 (4%)

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Paper IV

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Prevention of Anterior Cruciate Ligament Injuries in Female Team Handball Players: A Prospective Intervention Study Over Three Seasons

*Grethe Myklebust, MSc, PT, *†Lars Engebretsen, MD, PhD, *Ingeborg Hoff Brækken, MSc, PT, *Arnhild Skjølberg, PT, *Odd-Egil Olsen, MSc, PT, and *Roald Bahr, MD, PhD

**Oslo Sports Trauma Research Center, Norwegian University of Sport and Physical Education, and †Oslo Orthopedic University Clinic, Oslo, Norway*

Objective: To assess the effect of a neuromuscular training program on the incidence of anterior cruciate ligament injuries in female team handball players.

Design: Prospective intervention study.

Setting: Female team handball: Division I–III in Norway.

Participants: Players from the three top divisions: control season (1998–1999), 60 teams (942 players); first intervention season (1999–2000), 58 teams (855 players); second intervention season (2000–2001), 52 teams (850 players).

Intervention: A five-phase program (duration, 15 min) with three different balance exercises focusing on neuromuscular control and planting/landing skills was developed and introduced to the players in the autumn of 1999 and revised before the start of the season in 2000. The teams were instructed in the program and supplied with an instructional video, poster, six balance mats, and six wobble boards. Additionally, a physical therapist was attached to each team to follow up with the intervention program during the second intervention period.

Main Outcome Measures: The number of anterior cruciate ligament injuries during the three seasons and compliance with the program.

Results: There were 29 anterior cruciate ligament injuries during the control season, 23 injuries during the first intervention season (OR, 0.87; CI, 0.50–1.52; $p = 0.62$), and 17 injuries during the second intervention season (OR, 0.64; CI, 0.35–1.18; $p = 0.15$). In the elite division, there were 13 injuries during the control season, six injuries during the first intervention season (OR, 0.51; CI, 0.19–1.35; $p = 0.17$), and five injuries in the second intervention season (OR, 0.37; CI, 0.13–1.05; $p = 0.06$). For the entire cohort, there was no difference in injury rates during the second intervention season between those who complied and those who did not comply (OR, 0.52; CI, 0.15–1.82; $p = 0.31$). In the elite division, the risk of injury was reduced among those who completed the anterior cruciate ligament injury prevention program (OR, 0.06; CI, 0.01–0.54; $p = 0.01$) compared with those who did not.

Conclusions: This study shows that it is possible to prevent anterior cruciate ligament injuries with specific neuromuscular training.

Key Words: Anterior crucial ligament injury—Prevention—Team handball—Neuromuscular training—Menstrual status.

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INTRODUCTION

Anterior cruciate ligament (ACL) injuries are a problem in many team sports, particularly among women.[1–3] The risk of rupturing the ACL is five times higher among women than among men, and the gender difference is even higher at the elite level than in lower divisions.[4,5] Unfortunately, with a reported incidence as high as 1.6 injuries per 1,000 player-hours for elite female players during matches, team handball is no exception.[5] This is a figure at least as high as that reported from other team sports.[1–3,6]

So far, few studies have examined the short- and long-term consequences after an ACL injury in elite athletes. The return rate to sport has been reported to range between 30% and 50%.[7,8] In a recent study from Norwegian team handball, we show that the return rate was 58% in surgically treated patients and 82% in nonsurgically treated patients.[9] However, the same study shows that as many as half of the injured players reported significant problems with instability, pain, and loss of range of motion when examined 8–10 years after their injury.

One potential long-term problem after an ACL injury, whether the treatment is surgical or nonsurgical, is osteoarthritis to the knee. In a review, Gillquist and Messner[10] concluded that the prevalence of radiographic gonarthrosis is increased after all types of knee injuries compared with the uninjured joint of the same patient. A total rupture of the ACL seems to increase the risk tenfold compared with an age-matched uninjured population,[10] and gonarthrosis seems to occur despite the ability to rectify the instability surgically. We still lack evidence to suggest that ACL reconstruction decreases the rate of

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Address correspondence to Grethe Myklebust, PT, Oslo Sports Trauma Research Center, University of Sport and Physical Education, 0806 Oslo, Norway. E-mail: grethem@nih.no

posttraumatic osteoarthritis in the knee.[11] It may even be hypothesized that an effective ACL reconstruction increases the risk of future osteoarthritis by enabling the athlete to return to high-performance pivoting sports: either through reinjury or due to the high demands put on the knee. In our follow-up study on team handball players, approximately 50% of the injured players had radiologic signs of osteoarthritis 8–10 years postinjury.

Because most of the ACL injuries are noncontact injuries (approximately 80% of the injuries occur in a plant and cut situation or in a landing after a jump shot),[4,5] we hypothesized that improving awareness of the knee position, balance, and cutting and landing technique could reduce the frequency of ACL injuries. Balance board training has been used as an injury prevention model in several studies of injuries to the lower extremity, and some had good results.[12–15] Caraffa et al.[12] recently demonstrated a remarkable reduction of ACL injury rate in Italian male soccer players after introducing a proprioceptive training program using exercises on wobble boards. However, Soderman et al.[16] have not demonstrated any effect of a balance board training program on the incidence of injuries to the lower extremity in a randomized study on female soccer players. Hewett et al.[17,18] observed a reduced incidence of severe knee injuries in female volleyball players using a 6-week jump training program. They focused on changing landing technique to decrease forces by teaching neuromuscular control of the lower extremity during landing.

Because the long-term consequences of an ACL injury are serious and team handball is a high-risk sport, there is an urgent need to develop effective prevention strategies. Thus, our aim was to assess the effectiveness of a neuromuscular training program on the incidence of ACL injuries in female team handball players. The program was designed to improve awareness and knee control during standing, cutting, jumping, and landing.

METHODS

Study Design

This intervention study covers three consecutive seasons of the three top divisions in the Norwegian Handball Federation. During the first season (control season, 1998–1999) baseline data were collected on the incidence of ACL injuries. Then, an ACL injury prevention program was introduced before the start of each of the following two seasons (first intervention season, 1999–2000; second intervention season, 2000–2001). Injury registration was continued throughout the intervention seasons to assess the effectiveness of the prevention program.

The Data Inspectorate and the Regional Ethics Committee for Medical Research approved the study, and the injured players gave their written consent to provide medical information from hospital records.

Participants

The Norwegian Handball Federation league system ranks the participating teams according to their skill level into four division levels. Normally, 12 teams play in the elite division, 12 teams play in second division, and 12 teams play in each of four third division conferences. All the teams in the three top divisions were asked to participate in the study, except for teams from Northern Norway that were excluded for practical reasons. Each conference plays a double round-robin competition format during the season from mid-September to mid-April, and two teams advance and two teams are relegated between divisions according to their final league standing at the end of each season. In addition, most teams participate in a single-elimination cup tournament for the Norwegian Cup Championship, and the teams can play in a number of national and international tournaments throughout the season.

During the control season (1998–1999), 60 teams (942 players) took part in the injury registration: 12 teams in the elite division, 12 in the second division, and 36 in division three. In 1999–2000, the first intervention season, 58 teams (855 players) participated: 12 teams in the elite division, 13 in the second division, and 33 in division three (two clubs withdrew their team, and one declined to participate in the study). During the second intervention season (2000–2001), there were 52 teams (850 players) taking part: 12 teams in the elite division, 11 in the second division, and 29 in division three (four clubs withdrew and four teams declined). In other words, a total of six teams declined to participate in the study during the two intervention seasons. This amounts to 5% of the potential participating teams and is unlikely to have introduced any selection bias.

Anterior Cruciate Ligament Injury Prevention Program

An ACL injury prevention program with three different sets of exercises (Figs. 1–3) was developed, each set with a five-step progression from easy to more difficult (Table 1). Before the first intervention season (1999–2000), the teams were visited once in the preparatory period. They were supplied with an instructional video, posters, six balance mats, and six wobble boards. The teams were instructed to use the program three times weekly during a 5- to 7-week training period and then once a week during the season. The coaches were responsible for carrying out the program. They were also asked to record the total number of ACL injury prevention training sessions the team completed.

After evaluating the 1999–2000 season, we decided to continue the intervention but now with improved control over the quantity and quality of the ACL prevention program. The teams in the elite division all had physical therapists working closely with the teams, but few teams in the lower divisions had established a relationship with a physical therapist. We therefore recruited physical therapists to supervise each of the teams. All of the physical therapists participated in an 8-hour seminar in which they were given theoretical and practical training on how to conduct the ACL injury prevention program, as well as on the procedures of data collection. The physical therapists were asked to attend team training sessions three times a week for a 5- to 7-week period and

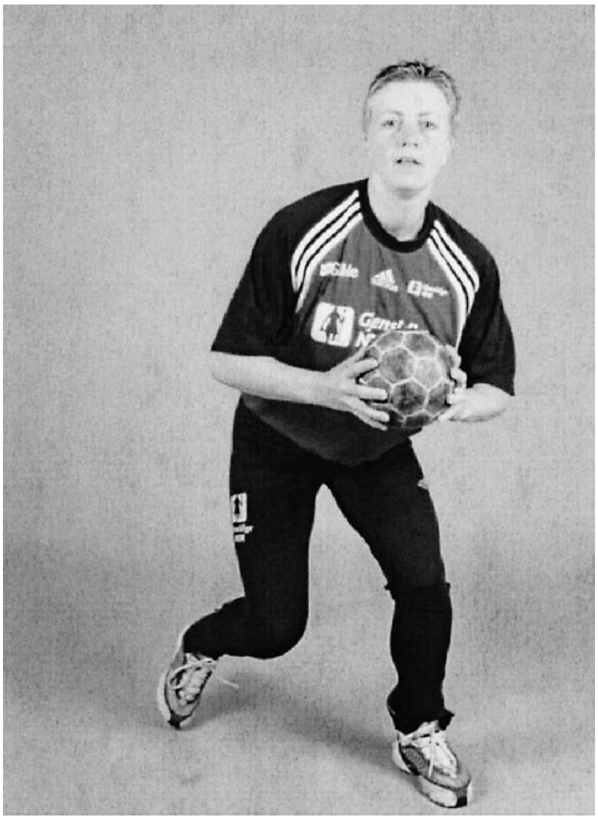

FIG. 1. Example of a floor exercise.

then once a week during the season to supervise the training program. They were also asked to record individual attendance during each of the ACL injury prevention sessions. Videos and posters were given to all of the teams. New teams were supplied with balance mats and wobble boards.

During the training sessions the teams were divided into three groups: one doing the floor exercises, one using wobble boards (disc diameter, 38 cm; Norpro, Notodden, Norway), and one using balance mats (40 × 50 cm, 7 cm thick; Alusuisse Airex, Sins, Switzerland). They changed positions every 5 minutes, for a total duration for the program of approximately 15 minutes. When performing one-leg exercises the players were told to change legs after approximately 15 seconds.

Some modifications were made to some of the training exercises before the second intervention season based on feedback from players and coaches after the first season. The changes aimed to make the exercises more specific to team handball, as well as more challenging. However, the focus of the exercises (i.e., to improve awareness and knee control during standing, cutting, jumping, and landing) did not change. The players were encouraged to be focused and conscious of the quality of their movements, with emphasis given to core stability and hip and knee position in relation to the foot (the "knee over toe" position). The players were also asked to watch their partner closely and to give feedback to each other during training.

Injury and Exposure Registration

During all three seasons the coaches and/or the team physical therapists were asked to report all ACL injuries, and they were contacted by telephone every 1–2 months to ensure that no knee injuries were missed. Players with suspected ACL injuries (i.e., knee injuries that caused more than 1 week of missed participation in training or matches) were interviewed by trained physical therapists, either in person or by telephone, using a standard questionnaire. Among the information requested in each case were personal data, menstrual history, and mechanism of injury. The menstrual cycle date was adjusted to an average cycle length of 28 days, with day 1 of the cycle designated as that day on which bleeding began. Injuries were classified as occurring in four different menstrual phases (day 1–7, menstrual phase; day 8–14, follicular phase; day 15–21, early luteal phase; day 22–28, late luteal phase).

Each case of a suspected ACL injury was either self-referred or referred by us for examination by an orthopedic surgeon, which included, in most cases, an arthroscopic examination and magnetic resonance imaging. The patients' medical records were obtained to confirm the diagnosis.

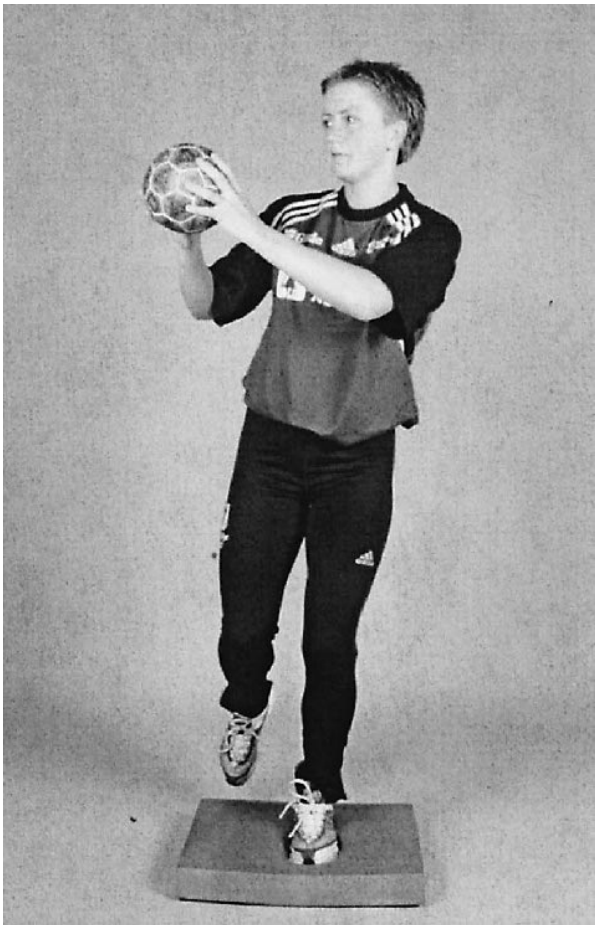

FIG. 2. Example of a mat exercise.

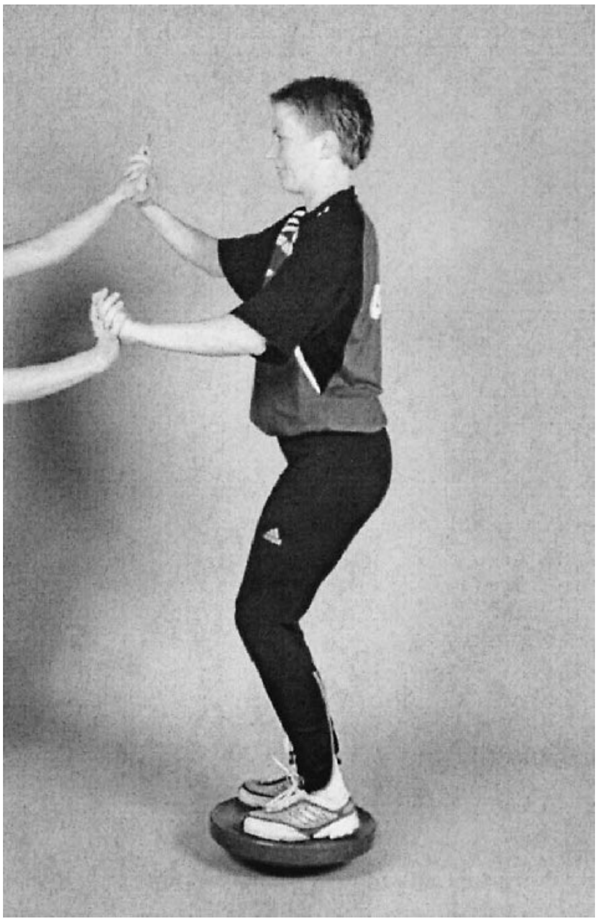

FIG. 3. Example of a wobble board exercise.

The coaches supplied information on the training schedule and attendance, number of official training games, tournament games, and cup and league games during each of the seasons. Competition exposure for each team was calculated as the number of games multiplied by the duration of each game (some tournament games lasted less than the regulation time of 2 × 30 minutes) multiplied by seven players. Training exposure was calculated based on the average weekly number of training hours multiplied by the average attendance for training sessions reported by the coaches. In the second intervention season, the physical therapists registered every training session in which the players performed the ACL injury prevention program.

Injuries reported from August 15 to May 31 (the ACL injury prevention program did not start until early August) were included to compare the injury incidence between the three seasons. Injury incidence was calculated as the number of ACL injuries reported per 1,000 player-hours (competition and/or training, as appropriate).

Statistical Methods

To fulfill the compliance requirement, the teams had to have conducted a minimum of 15 ACL injury prevention sessions during the 5- to 7-week period with more than 75% player participation. For nominal categorical data, a χ^2 test or Fisher exact test was used to determine whether there were significant differences between groups. Comparisons between rates were tested using a Walds test. An alpha level of 0.05 was considered to be statistically significant.

RESULTS

Anterior Cruciate Ligament Injuries

During the control season there were 29 ACL injuries, there were 23 injuries during the first intervention season (1999–2000; OR, 0.87; CI, 0.50–1.52; $p = 0.62$ vs. the control season, Walds test), and there were 17 injuries during the second intervention season (OR, 0.64; CI, 0.35–1.18; $p = 0.15$ vs. the control season; Table 2). The corresponding total injury incidence was 0.14 ± 0.05 per 1,000 player-hours (control season), 0.13 ± 0.06 per 1,000 player-hours (first intervention season), and 0.09 ± 0.06 per 1,000 player-hours (second intervention season; Table 2). In the elite division, there were 13 injuries during the control season, six injuries during the first intervention season (OR, 0.51; CI, 0.19–1.35; $p = 0.17$ vs. the control season), and five injuries in the second

TABLE 1. *Final anterior cruciate ligament injury prevention program*

Floor exercises
Week 1: Running and planting, partner running backwards and giving feedback on the quality of the movement, change position after 20 s
Week 2: Jumping exercise—right leg–right leg over to left leg–left leg and finishing with a two-foot landing with flexion in both hips and knees
Week 3: Running and planting (as in week 1), now doing a full plant and cut movement with the ball, focusing on knee position
Week 4: Two and two players together two-leg jump forward and backwards, 180° turn and the same movement backwards; partner tries to push the player out of control but still focusing on landing technique
Week 5: Expanding the movement from week 3 to a full plant and cut, then a jump shot with two-legged landing
Mat exercises
Week 1: Two players standing on one leg on the mat throwing to each other
Week 2: Jump shot from a box (30–40 cm high) with a two-foot landing with flexion in hip and knees
Week 3: "Step" down from box with one-leg landing with flexion in hip and knee
Week 4: Two players both standing on balance mats trying to push partner out of balance, first on two-legs, then on one leg
Week 5: The players jump on a mat catching the ball, then take a 180° turn on the mat
Wobble board exercises
Week 1: Two players standing two legged on the board throwing to each other
Week 2: Squats on two legs, then on one leg
Week 3: Two players throwing to each other, one foot on the board
Week 4: One foot on the board, bounding the ball with their eyes shut
Week 5: Two players, both standing on balance boards trying to push partner out of balance, first on two legs, then on one leg

TABLE 2. *Intention-to-treat analysis*

	Match						Training					
	Match exposure (h)		ACL injuries		Incidence		Training exposure (h)		ACL injuries		Incidence	
Season	All divisions	Elite division	All divisions	Elite division	All divisions	Elite division	All divisions	Elite divisions	All divisions	Elite division	All divisions	Elite division
1998–1999	15,547	3,941	23	11	1.48	2.79	193,389	64,491	6	2	0.03	0.03
1999–2000	14,854	3,822	17	4	1.14	1.05	157,838	48,830	6	2	0.04	0.04
2000–2001	12,865	3,822	14	5	1.09	1.31	173,940	67,499	3	0	0.02	0.00

Total exposure, number of anterior cruciate ligament (ACL) injuries, and injury incidence during matches (including official and unofficial matches) for all divisions and the elite division for the control season (1998–1999), intervention season I (1999–2000), and intervention season II (2000–2001). Match exposure has been calculated as the number of matches multiplied by the duration of each match multiplied by seven players on each team. The incidence is reported as the number of injuries per 1,000 playing hours.

intervention season (OR, 0.37; CI, 0.13–1.05; $p = 0.06$ vs. the control season; Table 2).

Five (7.2%) of the players injured their ACL for the second time, and 11 (16%) had injured the ACL in the other knee previously, all while playing team handball. The injured players were 22 ± 4 (SD) years old.

Compliance With Anterior Cruciate Ligament Injury Prevention Program

In the 1999–2000 season, 26% of the teams fulfilled the compliance criteria, with more than 15 ACL prevention sessions and 75% player participation. In the elite division, the corresponding value was 42%. In the 2000–2001 season, the overall compliance for the three divisions was 29% (50% in the elite division).

Of the 23 players injured during the first intervention season, 11 of the players had performed the program as prescribed, and three of 17 injured players in the second intervention season had followed the program as prescribed. When comparing the risk of injury during the second intervention season (during which individual training records were collected by the physical therapists) between players who did or did not complete the ACL injury prevention program for the entire cohort, there was no difference between those who complied and those who did not comply (OR, 0.52; CI, 0.15–1.82; $p = 0.31$, Fisher exact test; Table 3). However, in the elite division, the risk of injury was reduced among those who completed the ACL injury prevention program (OR, 0.06; CI, 0.01–0.54; $p = 0.01$; Table 3).

Injury Mechanisms

Fifty-eight (84%) of the injuries occurred during the attacking phase, and 10 (16%) occurred when performing defensive actions. Fifty-one (74%) of the players were handling the ball at the time of injury. Of the injured players, 39 (57%) were back players, 19 (28%) were wing players, four (6%) were line players, and five (7%) were goalkeepers.

Thirty-three (48%) of the injuries were reported as contact and 35 (51%) as noncontact injuries. We observed a reduction in the total number of noncontact injuries from 18 injuries in the control season to seven injuries during intervention season II ($p = 0.04$, χ^2 test).

Menstrual History

A reliable menstrual history could be obtained in 46 of 69 cases, and of these, 28 used contraceptive pills. Of the 46 cases, 23 (50%) occurred in the menstrual phase, 12 (26%) in the follicular phase, five (11%) in the early luteal phase, and six (13%) in the late luteal phase ($\chi^2_{3\ df} = 17.3$; $p < 0.0001$). Among the 18 non-contraceptive users there were nine (50%) injuries in the menstrual phase, four (22%) in the follicular phase, one (6%) in the early luteal phase, and four (22%) in the late luteal phase ($\chi^2_{3\ df} = 7.3$; $p = 0.06$). The corresponding figures for the contraceptive users were 14 (50%) in the menstrual phase, eight (29%) in the follicular phase, four (14%) in the early luteal phase, and two (7%) in the late luteal phase ($\chi^2_{3\ df} = 12.0$; $p = 0.018$).

TABLE 3. *Per-protocol analysis*

	All divisions					Elite division				
	No training		Completed ACL injury prevention program			No training		Completed ACL injury prevention program		
Season	Noninjured	Injured	Noninjured	Injured	Total number of injuries	Noninjured	Injured	Noninjured	Injured	Total number of injuries
1998–1999	913	29 (3.1%)			29 (3.1%)	212	13 (6.1%)			13 (6.1%)
2000–2001	631	14 (2.2%)	260	3 (1.1%)[a]	17 (1.9%)	41	4 (8.9%)	175	1 (0.6%)[b]	5 (2.3%)

Number of anterior cruciate ligament (ACL) injuries for players who did or did not complete the ACL injury prevention program presented for the entire cohort, as well as for the elite division separately, during the control season and intervention season II. Compliance during intervention season II (2000–2001 season) was determined based on individual weekly reports from the physical therapists. Data on individual compliance was not collected during intervention season I.

[a] Not significant.

[b] $p = 0.0134$ (Fisher exact test).

DISCUSSION

The main finding of this study was that there was a reduction in the incidence of ACL injuries from the control season to the second intervention season among the elite players who completed the training program. We also found a significant reduction in the risk of noncontact ACL injuries.

Methodological Considerations

There are several factors that must be considered when interpreting the results from an intervention study like this. First, it was not possible to plan this investigation as a randomized study because our power calculations showed that we would have needed approximately 2,000 players to detect a 50% reduction in ACL injuries. Even using a preintervention/postintervention comparison, we needed to include almost every team in the three upper divisions in Norway to achieve adequate statistical power. Teams in the fourth divisions, the only other group available for inclusion, do not practice sufficiently and play too few matches to have been used as study subjects.

It could be claimed that the high number of ACL injuries in the control season or the reduction after intervention is a coincidental result of natural variation and that we could expect a reduction in the following season independent of the intervention. Although we have not systematically collected data on potential confounding variables, such as floor type, shoe type, previous knee injuries, age, or coaching style, during the study period, we do not think there were substantial changes that can explain our findings. Prospective studies in Norwegian team handball have shown an increase in the number of ACL injuries from the late 1980s up to the late 1990s, which supports the fact that the intervention was effective among those who did perform the exercise. Also, the study shows a downward trend in the number of injuries during the study period, as compliance seemed to improve.[4,5] The injury rate observed in the control season, 0.14 ACL injuries per 1,000 hours, is lower than in our study from 1993–1996 (i.e., 0.31 ACL injuries per 1,000 hours).[5]

Second, in any epidemiological study, the reliability of the injury and exposure registration is critical. The current study was carried out using a prospective study design, in which the teams were requested to report any knee injury as soon as it occurred. In addition, the investigators remained in close contact with the team coaches and physical therapists throughout the study period. Also, the players were covered by the compulsory injury insurance policy of the Norwegian Handball Federation, and all insurance claims were examined to identify additional ACL injuries. Even so, there is always a possibility that an injury may have been overlooked. However, an ACL injury usually causes pain, swelling, and disability, and it is unlikely that a player may have developed an injury and been able to continue playing without the need for medical follow-up. Moreover, all of the reported ACL injuries were later verified arthroscopically, and reconstructive surgery was performed. It is therefore highly unlikely that we have recorded false-positive ACL injuries during the study period.

With respect to exposure registration, it was not possible to base this on individual attendance records for all practices and matches during the study period. Data on the number of matches were obtained from the coaches, including out-of-season tournaments and training matches, which should ensure good reliability. The training data are based on the average number of training hours per week reported by the coaches. We have received player lists from each team, and the exposure registration has been adjusted for training attendance.

Effect of the Training Program

Although there was a trend toward a reduction in the number of ACL injuries during the three seasons, it was not statistically significant ($p = 0.15$ for all division and $p = 0.06$ for the elite division). However, we did observe a statistically significant difference in injury rates in the elite division when we compared those players who completed the program with those who did not. It could be argued that there was a selection bias—that the teams who completed the program were more conscious of the risk of ACL injuries and therefore behaved differently in other ways as well. However, it is probably more likely that the teams that completed the program were those that had experienced significant problems with ACL injuries in the past. An ACL injury in team handball typically occurs in a noncontact situation in which the player performs a plant and cut movement or lands after a jump shot.[19,20] The fact that we found a decrease in the number of noncontact injuries is promising because these are the situations that the ACL injury prevention program was designed to prevent.

One explanation for the better results among the elite players could be the fact that these players have five to 10 practice sessions per week and therefore have the opportunity to achieve "enough" ACL injury prevention training to have protective effect. We were somewhat surprised by the low compliance in the study because the problem of ACL injuries has received a lot of attention from the media and within the handball community.[4,5] Despite the high incidence of injury, the dire future consequences to knee function in injured players,[9] and close follow-up of the teams by physical therapists, acceptable compliance was achieved in less than half of the players. It is tempting to speculate that players perceive the injuries as less serious than they may be in the long term—i.e., they believe that the only consequence is having to undergo surgery and 6–9 months of missed participation. At least this is how a case is often portrayed in the media. We may have to communicate even more clearly that although the ensuing instability after an ACL injury can be rectified surgically, future normal knee biomechanics and function usually cannot be ensured. The results also demonstrate the importance of recording individual compliance with the training program in a study of this nature.

This study shows that a preventive neuromuscular program works on the best and perhaps more motivated players, and that more intense follow-up is necessary to motivate the teams in the lower divisions to focus on preventive training. However, it may be easier to work with the younger players who have not yet established their motion patterns if the goal is to develop more "ACL friendly" movements.

Injury Prevention Program

The ACL intervention exercises were developed based on the exercises used by Caraffa et al.[12] on different wobble boards. We also chose to include exercises on a balance mat to further challenge neuromuscular control, and, finally, we included floor exercises thought to be applicable to team handball. The focus on the knee position (knee over toe) was supported by data from Ebstrup and Boysen-Moller[19] and Olsen et al.[20] Their video analyses of ACL injuries from team handball indicate that it could be beneficial not to allow the knee to sag medially or laterally during plant and cut movements or when suddenly changing speed. We also focused on two-feet landing after jump shot, with the emphasis on hip and knee flexion based on the Hewett et al.[17] data from volleyball. We also tried to influence the player's way of performing the two-feet plant and cut movement, aiming toward a narrower stance, as well as the knee over toe position. We have no data to detect any change in technique after the intervention, and this may be difficult to achieve in mature players. The prevention program tested is multifaceted and addresses many aspects of risk for injury (agility, balance, awareness of vulnerable knee positions, playing technique), and it is not possible to determine exactly which part of the program may be effective in preventing ACL injury. However, educating coaches to teach young players a more ACL-friendly way of doing the plant and cut movement, by not allowing their knees to sag medially when cutting and landing, could prove beneficial. Further studies are necessary to determine the effects of each program component on injury risk, as well as on potential physiological risk factors for injury (e.g., balance, joint position sense, strength, muscle recruitment patterns).

Compared with Caraffa et al.,[12] our results are not impressive, but it could depend on differences in sex, sport, level of play, surface, or the use of a different exercise program. However, it should be noted that no other groups have so far been able to duplicate the results obtained by Caraffa et al.[12] Soderman et al.[16] showed no effect of wobble board exercises on the incidence of lower extremity injuries in female soccer players. Actually, their intervention group had more ACL injuries than the control group.

Menstrual History

The observation of an apparent relationship between menstrual phase and ACL injury risk must be interpreted with caution because it is based on a small number of observations and because hormonal data to confirm menstrual status were not available. Also, the players' menstrual status was not recorded continuously throughout the study period, and in some cases a reliable menstrual history could not be obtained. However, the results from this study are similar to those from our previous study in team handball,[5] and they are in contrast to the results of Wojtys et al.,[21] who found an increased risk of ACL injury during the ovulatory phase. All of these studies should be interpreted with caution because they are small, and the players' menstrual status was uncertain. Based on their data, Wojtys et al.[21] suggested that the use of oral contraceptives increases the player's dynamic stability, and that this may reduce the risk of serious knee injury in high-risk athletes. Karageanes et al.[22] found no significant change in ACL laxity during the menstrual cycle and concluded that the menstrual cycle did not affect the ACL laxity in adolescent female athletes. Further studies are therefore necessary to examine this relationship, and although it is conceivable that hormonal fluctuations may have effects on ligamentous tissue, convincing evidence to support this hypothesis is not available.

CONCLUSIONS

Prevention of ACL injuries is possible with the use of neuromuscular training in female elite team handball players, but successful prevention depends on good compliance among the players. Further research is needed to determine the effect of each component of the training program on neuromuscular function and injury risk.

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