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

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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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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

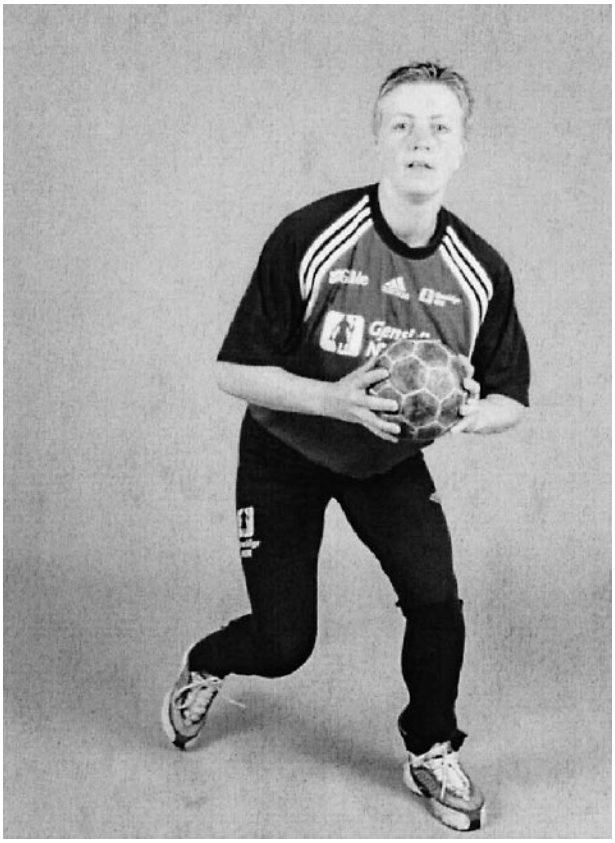

FIG. 1. Example of a floor exercise.

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.

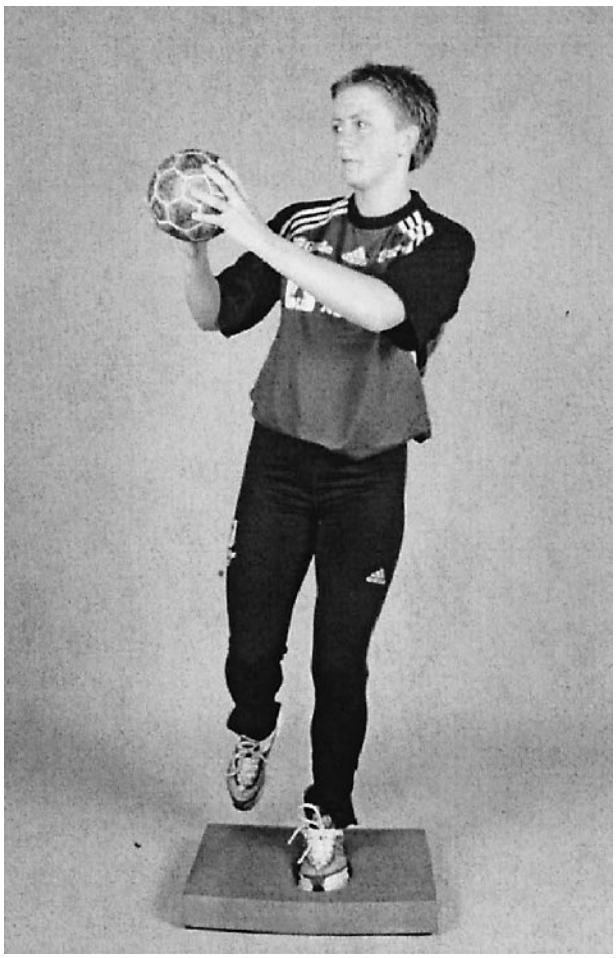

FIG. 2. Example of a mat exercise.

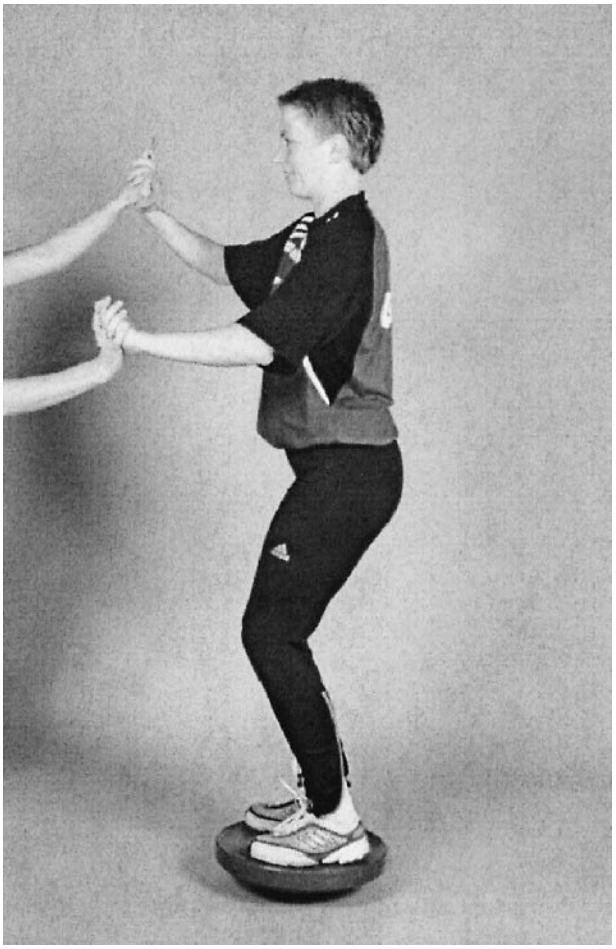

FIG. 3. Example of a wobble board exercise.

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		Total number of injuries	No training		Completed ACL injury prevention program		Total number of injuries
Season	Noninjured	Injured	Noninjured	Injured		Noninjured	Injured	Noninjured	Injured	
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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