Can a Nine Month Training Program Prevent Anterior Cruciate Ligament Injuries?

A Study on Adolescent Alpine Skiers

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Abstract

Background. Anterior Cruciate Ligament (ACL) injuries can have an influence on the rest of the person’s life, with difficulties to participate in sports or limit the choice of work and leisure activities. Earlier studies have successfully decreased ACL injuries with strength training in different sports, however no study have been made on competitive alpine ski racers. The purpose of the study is to see if a nine month strength training program for the lower extremities and core can increase strength and prevent ACL injuries in adolescents who compete in alpine skiing. Method. Twelve adolescents (mean age 13,1) trained a special designed training program for nine months, twice a week, to improve strength and control in the lower extremities and core. Eight adolescents (mean age 14,1) functioned as a control group (CG) and trained normal during the intervention time. Both groups performed the baseline- and end point test in April 2011 and April 2012. Result. Significant results were found in the training group, especially hamstring left and right (mean diff. 36,9sec P= 0,025 resp. 26,0sec P=0,021). The CG reported three knee injuries, while the TG none. Conclusion. Significant results are limited; however, the TG increased strength significant in the hamstrings, which is an important factor in preventing ACL injuries. Additionally, the CG had three knee injuries during the intervention while the TG had none, also suggesting that the training program was successful.
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In elite alpine skiers the ACL rupture often occurs after a combination of actions when landing from a jump (Bahr & Meahlum, 2004). This is also the case in other sports such as soccer, basketball, volleyball and handball where most of the ACL injuries occur without contact with other persons and with the knee near extension (Arendt et al. 1999; Boden et al., 2000; Griffin et al., 2000; Hewett et al., 1999; Noyes et al. 2011). In skiing there is one major difference when landing from a jump compared to above mentioned sports. Skiers come with very high speed when they jump. When skiers land they do not stop, but continue to slide forward with high speed. A hit on the back of the ski, concentric activation of the quadriceps and a light varus/valgus in the knee when landing with bodyweight to far back (Bahr et al. 2004) makes the top of the ski boot drive the tibia forward, which makes the skier lean backwards to a sitting position. This motion, also known as the Phantom foot (Fig.1), may lead to an ACL rupture (Johnson, 1995). At this position there is a deep knee flexion since hips are below the knees, most weight is placed on the inside edge of the downhill ski, which produce a internal rotation of the hyper flexed knee (Natri et al., 1999).

Emery (2003) argues that independent of sport, subjects older than 13 years old are at higher risk of injury than are children, also supported by Froholdt et al. (2009) who offer results saying that younger (6-12) athletes injure themselves more seldom than do older athletes (13-16). On the other hand, Deibert et al. (1998) conclude that alpine skiing children have 54% higher risk of injury than adults. In a recent published study by Westin et al. (2012) nearly 50% of the ski students in Swedish Ski High Schools had an injury during their time at the school. The knee joint was the most commonly injured body part. Moreover, out of the 431 skiers in the study, 304 reported a former injury when they entered the study. The result was also clearly showing the lower extremity as the most common injured body part.

According to Mandelbaum et al. (2005), complete ACL ruptures lead to knee instability, osteoarthritis, meniscus- and chondral surface problems. This is also supported by Bahr et al. (2004), who found that as many as 75% of all patients suffering from an ACL injury, at the same time suffer from meniscus problems. Further, 80% of all patients also suffer from bone contusion and 10% have cartilage problems which need treatment, after an ACL injury. Among the untreated injuries, about 70% get osteoarthritis after 10 years (Bahr et al. 2004).

1.1. Earlier studies preventing ACL injuries

Yu et al. (2005a) and Natri et al. (1999) state that there might be a correlation between non-contact ACL injuries and strength. Earlier studies have shown that neuromuscular training of lower extremities can result in less landing force, adduction- and abduction moments, but also a physiological effect with increased
hamstring to quadriceps ratio (Hewett et al. 1999). A number of studies found that strength training of muscles around the knee joint decreased ACL injuries in sports such as soccer and handball (Gilchrist et al. 2008; Hewett et al. 1999; Holcomb et al. 2007; Myklebust et al. 2003).

Myers & Hawkins (2010) argue for the importance to lower impact forces to reduce knee loading when landing from a jump. Further, their study decreased the peak tibial shear force, increased knee flexion angle and moved the centre of pressure towards the toes when landing after a high speed basketball jump. They therefore discuss the fact that it might be important to look at where the force is directed relative to the knee joint, more than reducing knee load. Chimera et al. (2004) also suggest that the improved muscle activation patterns after plyometric training can benefit dynamic joint stability.

1.2. **Strength training in children**

Research shows that children and adolescents who train strength do become stronger than children and adolescents who do not train strength (Blimkie et al. 1996; Falk & Tenenbaum 1996; Behringer et al. 2010; Weltman et al. 1986). In adults, strength training often leads to bigger muscles. However, the reason for increased strength in prepubescent children is not due to increased cross sectional area of the muscles, but due to better cooperation between the nervous system and the muscles (Ozmun et al. 1994). According to Faigenbaum et al. (1999, 2001) children do not need heavy resistance in their strength training to develop strength. High repetition–moderate load is sufficient. Ozmun et al. (1994) also found increased integrated electromyography (IEMG) activity, which may indicate increased motor unit recruitment, firing rate or firing patterns in pubescent children. Since many sports expose the athletes to high external forces, strength training is of importance. Strength training has more beneficial results than increased muscle strength. The ability to perform correct movement patterns and technique is often dependent on adequate strength, as well as the fact that the skeleton grows stronger following increased load. A strong body is therefore also at decreased risk of injury (Hejna & Rosenberg, 1982; Cahill & Griffith, 1978; Tonkonogi, 2007).

There are a very limited number of articles published about ski injuries and their prevention in competitive alpine skiing. The reason for the minimal amount of studies in competitive alpine skiing is questionable since Wojtys et al. (1998) found that out of eight different popular sports, 21% of the Anterior Cruciate Ligament (ACL) injuries occurred while skiing. According to Florenes et al. (2010) the knee is the most common injured body part in 36% of all alpine ski accidents among World Cup/Championship skiers (WC/WCS). Further, Flørenes et al. (2009) and Deibert et al. (1998) found that ACL injury is the most common diagnosis of all alpine ski injuries.

When considering above mentioned consequences of an ACL injury it is clear that it might have a major impact on whoever it concerns. According to Swedish National Knee Ligament Register (2011) adolescents as young as 13 years old are subjects to ACL injury. Same statistics show that girls injure themselves earlier than do boys. The highest numbers of ACL injuries are found in girls age 16 and in boys age 17. ACL injuries can influence the rest of the person’s life, with difficulties to participate in sports or limit the choice of work and leisure activities. Therefore, the purpose of this study is to see if a nine month strength training program for the lower extremities and core can increase strength and prevent ACL injuries in adolescents who compete in alpine skiing. The hypothesis is that strength training will increase the ACL injuries.
2. Method

2.1. Subjects
Two different teams were chosen since they have very similar training opportunities. They are both members of the same Association, compete in the same races and are the same age group (age 11-15), both with mixed gender (see table 1). Both teams come from mountain villages with access to training on snow/glacier all year around. The athletes compete at the highest level of their age. Athletes with former serious knee injuries, such as ACL or meniscus, were excluded from the study, as well as athletes with present injuries, stopping them from performing at their best at the baseline test.

2.1.1. Training Group (TG)
Out of 18 adolescents in the TG, 15 participated in the baseline test (April 2011). Three female athletes quit the team just before the test or could not participate on the date of the baseline test. After the baseline test, one more of the 15 athletes quit the team. That leaves 14 athletes (seven boys and seven girls) who did the baseline test and finished the training program. At the time of the end test (April 2012), two of the 14 athletes did not participate (personal reasons). That leaves 12 athletes (six boys and six girls) who completed the study.

2.1.2. Control group (CG)
Out of 19 adolescents in the CG, 14 participated in the first test (April 2011). Five athletes quit the team just before or could not participate on the date of the first test. Of the 14 athletes, two were excluded because of present injuries or former knee injury. This leaves 12 athletes (four boys and eight girls) who did the test and finished the training program. At the time of the second test (April 2012) four out of the 12 athletes did not participate (personal reasons). That leaves eight athletes (three boys and five girls) who completed the study.

2.2. Procedure
The intervention was performed between April 2011 (baseline test) and April 2012 (end test) covering one whole season. The TG and CG performed the tests at different days, however, not more than three days after each other. The training program for the TG started in the beginning of July 2011.

2.2.1. Health declaration
Before both baseline- and end test, both teams filled out a health declaration (see appendix 1) to find out about former injuries and present condition. They also received information about the survey before the baseline test, which had to be signed by the athletes and the parents of the athletes. The children were also informed that their participation was voluntary and that they could drop out at any time without a reason. Moreover, any information given by them would remain anonymous.

2.2.2. Injury questionnaire
Every injury in both TG and CG, which happened between 1st of August 2011 and 30th of April 2012, and kept the athlete away from training for more than one day, was registered in a questionnaire by the athlete. The athlete filled out a where the injury happened (at ski training, physical training or at ski race). They also filled in how it happened, what body part were injured, medical treatment and the injury severity. Injury severity was based on how many days the athlete was absent from training and racing, ranking 1-6, see appendix 2.
Table 1. Baseline Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Training group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of teams</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>No. of athletes</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Female</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Male</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Mean age, April 2012, y</td>
<td>13.1</td>
<td>14.1</td>
</tr>
</tbody>
</table>

2.3. **Testing Procedure**

The test started with seven minutes warm up for the whole body. The warm up exercises were running and doing different movements, such as indian jumps, skipping, high knees, kick in the bum, waving the arms, touching the floor, jumping and running backwards. No stretching was performed after warm-up. The athletes were divided into groups with 3-4 persons respectively. The seven different tests (see figure 2.) were based on Bahr et al. (2004). At each station there was a supervisor who instructed the athletes how to perform the test. After each group had performed the four first tests, the remaining three tests were performed. The tests were never performed with the same muscle group tested straight after each other. The test exercises were not the same as the training program exercises, to ensure that the TG got no advantage at the time of the end test.

**Standing long jump:** Two measure bands (Metri, Richter-Qualität, 20m) were taped parallel on the floor and a wooden stick was used to measure accurately. Test person stood with feet shoulder width and arms hanging free. Toes were placed just behind a line at the beginning of the measure bands. Test person bend the knee joint to 90° and then jumped forward as far as possible. The use of arms was voluntary. The landing had to be controlled, the feet should be parallel and no hands were allowed to touch the ground. The stick was placed on the heel furthest back and length was measured on both sides to get the right length of the jump. Test persons performed three jumps each and the mean length was counted. If the test person failed to stay in balance at landing the result was not counted.

*Figure 2. Six of the seven test stations, weight and height not shown* (Bahr & Mehlum, 2004)
Weight and height: For height, the test persons had to stand without shoes, with head, shoulders, bum and heels in contact with the wall behind them. The measure band (Metri, Richter-Qualität, 20m) was taped on the wall and the result was rounded off to half centimetres. For weight (Scale: Beurer Art.-Nr 722.01. typ. PS12 +0.6 kg), only shorts, t-shirt and socks were worn, and each test person was weighed twice to ensure a correct result.

Side bridge: The test people lay on optional side with their elbow directly under their shoulder, their hip on the ground and their feet on top of each other. On a given signal the hip left the ground and the test person stood on the elbow, lower arm and the side of one foot (not exactly the same as on the picture, figure 2). The other arm lay resting on the side of the body. There was a straight line from head to toe in both frontal and sagittal plane. The time was stopped when the position could no longer be kept clean, for example, when the hip was lowered or pointed back or the foot was dropped. One warning was given. The test was performed on both left and right side.

Balance and coordination test: A normal “gymnastic bench” (31cm high) was turned upside down and the test person had to stand on the 10 cm thick bar in the middle with feet shoulder width. The test person was provided with a volleyball and had to bounce it as many times as possible during 30 seconds. Only one trial was allowed. The legs and upper body had to be kept straight the whole time. If the ball was dropped, a new one was handed to the test person straight away, if the balance was lost, the test person could step up again. Every fall resulted in that one bounce was taken off the result. A dropped ball did not count as a bounce. It was allowed to use one or two hands to bounce the ball.

Hamstring test: A 40cm high bench plus a stop timer were used. Also carpets in different heights were provided for those test people who were smaller, to get the right angle in the knee and hip joint. The test persons were lying down on the carpet adjusting their body to 90° degrees in elbow, knee and hip joint. On a given signal the test person had to lift the whole back and bum, by pushing down one heel (optional) towards the bench. Only one heel, elbow and underarm could be in contact with ground/bench. This position had to be kept for as long as possible. When the 90° angle could no longer be kept or the bum or back touched the floor, the time was stopped. One warning was given. The test person had one trial on each leg.

Bridge: The test person lay on their stomach on a yoga mat with the elbow joint bent to 90° and their toes on the ground. On a given signal, the test person lifted the stomach, now standing only on elbows, lower arms and toes, completely straight from head to heel. The eye was kept towards the carpet, the shoulders were parallel and there was a natural curve in the spine. This position was kept for as long as possible. If technique decreased, one warning was given. Second time technique decreased the time was stopped. The test was performed once.

Sergeant jump: The test person started standing shoulder width with both big toes touching the wall and both hands reaching as high up as possible without the heels leaving the ground. The test person had magnesium on the fingers and the highest magnesium mark was detected. The test person turned 90° and stepped out 30 cm from the wall (marked with tape on the floor). The test person still stood shoulder width and then bent the knee joint to 90° and jumped as high as possible, touching the wall with their fingertips. The distance between the two magnesium marks were measured to get the jump height. Three jumps were performed three times with at least one minute rest in between. The three results were added together and divided by three to get a mean result.
2.4. The training program for the training group

The training program (see table 2) was designed to be easy to perform for everyone without the use of much equipment and independent of age, sex or maturity. The training program was performed twice a week during build up season (July – November) and once a week during competition season (December – March). The training program was changed every seventh week to assure that the kids increased in strength and did not get bored. Additionally, it was always performed as the first part of the physical training, as a longer warm up, and took 30 minutes. All exercises were described in detail and performed by the author at the first training of each phase. The team coach was then responsible for the training program during the remaining time. A sheet with written instructions and pictures for each exercise was provided for the coming trainings (see Appendix 3).

First the athletes performed seven minutes warm up with jogging and different flexibility exercises, plus some pulse increasing sprints at the end (see Appendix 3). Then the group was divided into smaller groups and put out on the five different stations. Each exercise was performed for one minute, three times, with 30 seconds rest in between. Since all exercises (except two hamstring exercises, see table 2) were counted in minutes instead of repetitions it was possible for individual increase of repetitions when the athlete learned the technique and improved strength. The athletes changed station after having completed three one minute sets of any given exercise. Some of the exercises were especially designed considering that the athletes are skiers, for example the side lunge/squat, and other exercises were made on one leg to minimize the dominant leg taking over and getting stronger. The exercises were basic in the beginning. However, as time went on and technique and muscles got stronger, the exercises got harder and more explosive. The exercises were performed as much as possible with bodyweight as resistance, only few exercises needed a weight or medicine ball.

Last, both TG and CG’s team coaches reported how many hours of physical training, ski training and amount of races they had performed during the period July 2011 and March 2012.
Table 2. Training program July 2011 - March 2012. For detailed program, see Appendix 3

<table>
<thead>
<tr>
<th>Warm up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seven minutes running with different exercises to warm up the whole body.</td>
</tr>
<tr>
<td>Indian jumps, skipping, side steps, high knees.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1</strong></td>
</tr>
<tr>
<td>1. Walking lunges with a stick behind the back to keep an upright position</td>
</tr>
<tr>
<td>2. Hamstring press on one leg, switch leg after 30 sec</td>
</tr>
<tr>
<td>3. Straight crunches with lower back pressed against the floor</td>
</tr>
<tr>
<td>4. Throw a medicine ball between each other or against a wall while standing on one leg, switch leg after 30 sec.</td>
</tr>
<tr>
<td>5. Squat with bum touching a bench</td>
</tr>
<tr>
<td><strong>Phase 2</strong></td>
</tr>
<tr>
<td>1. Walking lunges with weight and upper body rotation</td>
</tr>
<tr>
<td>2. Hamstring pull on Swiss ball</td>
</tr>
<tr>
<td>3. Stomach exercise with legs &quot;biking&quot;, lower back touches the floor</td>
</tr>
<tr>
<td>4. One leg dead lift, switch leg after 30 sec</td>
</tr>
<tr>
<td>5. One leg deep squat, switch leg after 30 sec</td>
</tr>
<tr>
<td><strong>Phase 3</strong></td>
</tr>
<tr>
<td>1. Lunges walking backwards</td>
</tr>
<tr>
<td>2. Nordic hamstring, work in pairs, 12 reps 3 sets / person</td>
</tr>
<tr>
<td>3. Swiss army knife</td>
</tr>
<tr>
<td>4. Core stabilization on Swiss ball. Lying down with straight legs on the ball, switch leg after 30 sec</td>
</tr>
<tr>
<td>5. Ice skating jumps</td>
</tr>
<tr>
<td><strong>Phase 4</strong></td>
</tr>
<tr>
<td>1. Jumping lunges</td>
</tr>
<tr>
<td>2. Dead lift with light bar</td>
</tr>
<tr>
<td>3. Sit ups with bar over the feet and behind the head</td>
</tr>
<tr>
<td>4. Side bridge with leg raise, switch leg after 30 sec</td>
</tr>
<tr>
<td>5. Squat with light bar on the neck</td>
</tr>
<tr>
<td><strong>Phase 5</strong></td>
</tr>
<tr>
<td>1. Telemark stepping up on a board with arms pending, switch leg after 30 sec</td>
</tr>
<tr>
<td>2. Explosive hamstrings with a medicine ball, work in pairs, 12 reps 3 set/person</td>
</tr>
<tr>
<td>3. Bridge and knee pull on a Swiss ball</td>
</tr>
<tr>
<td>4. Jump back and forth on one leg, knee control, switch leg after 30 sec</td>
</tr>
<tr>
<td>5. Side squat with weight, arms straight out from the body</td>
</tr>
<tr>
<td><strong>Phase 6</strong></td>
</tr>
<tr>
<td>1. Telemark steps from a board, switch leg after 30 sec</td>
</tr>
<tr>
<td>2. Explosive hamstrings with one foot on a bench, change leg each time</td>
</tr>
<tr>
<td>3. Diagonal sit ups with one leg on the other knee</td>
</tr>
<tr>
<td>4. 180 degree jumps with both feet, knee control</td>
</tr>
<tr>
<td>5. Explosive squat with weight in one hand, switch arm after 30 sec</td>
</tr>
</tbody>
</table>

2.5. **Statistical analysis**

Results are presented as mean and ± SD. To compare differences in each group, an independent and paired-samples t-test was used. Significant level was set at p < 0.05, and the analyses were conducted using the IBM SPSS statistics 20 (SPSS, Inc, Chicago, IL).

3. **Results**

Both TG and CG increased their long jumping ability significantly (mean difference 15.0±7.6 respectively; 14.4±6.5 P= 0.000) during the 12 months study. The CG was both taller and heavier than TG at the time of the first and second tests (see table 2). The TG increased side bridge right (mean difference 18sec±
42.3\(P = 0.167\)) while they stayed the same on side bridge left (mean difference, -1.1sec \(\pm 59.2 P = 0.951\)). CG decreased in strength on both right and left side of the side bridge (mean difference, -35.9sec\(\pm 37.8 P =0.031\) respectively -46.6sec\(\pm 16.0 P=0.000\)). TG increased its balance and coordination ability significantly (mean difference 13.2\(\pm 11.6 P =0.002\)) while CG also had an increase, however not significant (mean difference 9.4\(\pm 8.7 P=0.018\)). TG increased their hamstring strength on both left and right leg (mean difference 36.9sec\(\pm 49.3 P=0.025\) respectively 26.0sec\(\pm 33.3 P=0.021\)). CG decreased strength on the left leg (mean difference -31.8sec\(\pm 31.3 P=0.024\)) while increased strength in the right leg (mean difference 7.9sec\(\pm 28.2 P=0.456\)). The TG’s absolute hamstring strength (mean L: 150.5sec resp. R: 154.7sec) is almost double compared to CG (mean L: 83.9sec resp. R: 85.1sec). The bridge strength increased in CG while decreased in TG (mean difference 34.0sec\(\pm 115.5 P=0.433\) respectively -13.9sec\(\pm 61.8 P=0.452\)). Although, the absolute strength in TG is better than CG (mean time in seconds TG; 217.7 respectively CG; 202.5). In the last test, sergeant jump, both groups increased their jumping strength significantly (mean difference TG; 11.1cm\(\pm 2.3 P=0.000\) CG; 10.1cm\(\pm 2.7 P=0.000\)).

Table 3. Test results

<table>
<thead>
<tr>
<th></th>
<th>Training group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre 2011</td>
<td>Post 2012</td>
</tr>
<tr>
<td>Weight</td>
<td>38.1</td>
<td>42.0</td>
</tr>
<tr>
<td>Height</td>
<td>149.4</td>
<td>155.2</td>
</tr>
<tr>
<td>Long jump</td>
<td>177.3</td>
<td>192.3</td>
</tr>
<tr>
<td>Sidebridge R</td>
<td>119.8</td>
<td>137.9</td>
</tr>
<tr>
<td>Sidebridge L</td>
<td>120.8</td>
<td>119.8</td>
</tr>
<tr>
<td>Balance</td>
<td>46.9</td>
<td>60.1</td>
</tr>
<tr>
<td>Hamstring L</td>
<td>113.6</td>
<td>150.5</td>
</tr>
<tr>
<td>Hamstring R</td>
<td>128.7</td>
<td>154.7</td>
</tr>
<tr>
<td>Bridge</td>
<td>231.6</td>
<td>217.7</td>
</tr>
<tr>
<td>Sergeant jump</td>
<td>26.6</td>
<td>37.7</td>
</tr>
</tbody>
</table>

*Significant value
** Strength decrease

There were seven injuries in the CG (four girls and three boys) and six injuries in the TG (four girls and two boys). In each group, two injuries happened during ski training, two injuries happened during physical training in the TG while two in the CG. No injuries occurred during the training program in the TG. The CG had two accidents at race while TG had none. Two injuries in the TG happened outside team training, either in school or at free time. There were no knee injuries in the TG while three in the CG, two foot injuries in the TG and one in the CG. Both teams had one injury each in the arm/hand, shoulder and calf (tibialis anterior). The TG also had one back injury. The CG reported a higher amount of serious injuries than the TG. Four out of the seven injuries in the CG kept the athlete away from training more than 28 days. The TG had one injury which took up towards two weeks to recover from (see table 4).
Table 4. Injuries in both TG and CG August 2011 until March 2012.

<table>
<thead>
<tr>
<th></th>
<th>Training group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total amount of injured athletes:</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Injured female:</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Injured male:</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Injuries at ski training</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Injuries at ski racing</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Injuries during physical training</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Injuries during other activity</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Serenity of injury nr.1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Serenity of injury nr.2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Serenity of injury nr.3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Serenity of injury nr.4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Serenity of injury nr.5</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Serenity of injury nr.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Amount of foot injuries</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Amount of calf injuries</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Amount of knee injuries</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Amount of hip/groin injuries</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Amount of back injuries</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Amount of shoulder injuries</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Amount of head injuries</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Amount of arm/hand injuries</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The athletes of the TG and CG trained similar amount of hours. TG 183 resp. CG 203 hours of physical training, 373 resp. 339 hours of ski training and competed in 24 races during the nine months, see table 5.

Table 5. Training hours and amount of races in TG and CG from July 2011 until March 2012.

<table>
<thead>
<tr>
<th></th>
<th>Training group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ski training, hours (July-March)</td>
<td>373</td>
<td>339</td>
</tr>
<tr>
<td>Physical training, hours(July-March)</td>
<td>183</td>
<td>203</td>
</tr>
<tr>
<td>Ski races, amount(December-March)</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Sport hours in school/week:</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

4. Discussion

The hamstring is an ACL agonist when the leg is flexed, which helps resist forces that can strain the ACL (Huston & Wojtys, 1996). Studies have found that the hamstring musculature is important when it comes to preventing ACL injuries (Hewett et al. 1999, Holcomb et al. 2007). The biggest difference between TG and CG in this study at the end test in April 2012 was hamstring strength, in both left and right leg. TG increased their strength significantly in both left and right legs hamstring, while no such results could be seen in the CG. It is possible that hamstring exercises are forgotten in adolescents training. Since most ACL injuries in skiing individuals happen in the phantom foot, hamstring strengthening should be a part of every training session.

Many exercises in this study’s training program were performed on one leg at the time to ensure that the increase in strength was similar in both legs. One study suggests that imbalance in strength between left and right leg might cause ACL injuries, especially in females (Negrete et al. 2007). The TG got more equally strong in both legs hamstring (mean 150,5sec resp. 154,7sec), indicating that one leg exercises have been
successful. Although, Östenberg et al. (1998) found that there were no significant difference in strength between left and right leg (dominant versus non dominant leg) in female soccer players.

Balance and coordination results increased significantly in both groups, probably because of better coordination which comes with age and experience. The reason for poor results in core exercises remains unclear. Both bridge and side bridge are tests with a subjective assessment. Maybe the test leaders were stricter at the second test?

Many exercises had a major focus on how the knee acted in relationship to the foot and hip when performing jumps and normal strength exercises. Hips should be vertical and the knee should not wobble or go over the feet, not in varus nor valgus. Other studies conducted in other sports have had success when improving awareness of the knee stability during strength training, jumping and landing (Myklebust et al. 2003; Myers & Hawkins, 2010). When watching the athletes in the TG, it was clear that they improved technique and awareness of their knees position during this period of time. Future research should investigate if improved technique at physical training is convertible to skiing on snow; if their landing technique and awareness of knee position is also improved when skiing.

During this study there were no ACL injuries in either of the groups. Nevertheless, the CG had three injuries concerning the knee, while the intervention group had none. Is this because of the training program or just coincidence? The study contains a small number of both control and training subjects which makes it hard to say, even so, strength training is proved to be an efficient way of preventing injuries concerning the knees (Hewett et al. 1999; Olsen et al. 2005; Holcomb et al 2007). A study containing more teams would probably give more trustworthy results.

The CG reported four injuries as number five on the scale of how serious they were, meaning the athlete could not train for more than 28 days. The TG only had one injury that took about two weeks to recover from. Further, there were two athletes in the CG who got two injuries close after each other (1-2 months). The first athlete injured the knee twice; the other athlete first broke the arm and then tore a ligament in the shoulder. None reported treatment by a physiotherapist, and one can assume bad rehabilitation or to quick come back from the first injury.

According to this study, most injuries occurred during physical training (TG, n=3 CG, n=2) or at ski training (TG, n=2 CG, n=2). That is a surprising result when compared to Flørenes et al. (2009) who found that among world cup alpine skiers, most injuries occur at competition and least injuries occur at training off snow (physical training). Could that be because adolescents play more during their physical training while adults do more strength training? There were no injuries reported during this study’s’ knee training program, supporting that strength training is a safe activity for children and adolescents (Hamill, 1994).

Strength training twice a week is found to show better results than strength training once a week (Faigenbaum et al. 2002). Even if this study got a number of significant results, it is possible that the results would have been even more significant if they would have had more physical training during the competition season as well. Strength training is perishable and strength decreases quickly if not maintained, especially in grown-ups. However, among children, mixed results have been found. Faigenbaum et al. (1996) found that strength decreased again after an eight week break among children age 7-12.
Overall, skiers say they find it hard to find time to train their physics during competition season. The author of this study think they prioritize wrongly and are scared of losing time on the slope, training technique. Moreover, especially children/adolescents would probably profit from a stronger body and better motion patterns when skiing, thanks to more strength training. If nothing else, they can be troubled by less injury, and that means more time on the slope in the long run. This is also supported by Yu et al. (2005b) and Nichols et al. (2001) who found that bone mineral density is developed in a positive way, while Natri et al. (1999); Hewett et al. (1999) and Holcomb et al. (2007) reported fewer injuries after strength training programs in different sports.

The training program in this study focused on increasing strength, balance and coordination in lower extremities and core. Better strength/neural adaptation, balance and coordination might not help if a skier crashes in high speed; on the other hand, the author believes that it might prevent the skier to even come in that devastating situation. With a faster neural adaptation, better coordination and balance, the skier can react on inputs from the surrounding and adjust the movement to protect itself from falling. A stronger muscle can adjust movements who are not perfect and resist the forces pulling the skier backwards and down in to the phantom foot.

There are many factors that affect whether strength training is successful or not. Some factors are changeable, such as duration, intensity and frequency of the training program, while some are not, such as gender, age, maturation and genes. Children always gain strength since they are growing (Tonkonogi, 2007; Weltman et al. 1986); therefore, it is hard to say whether the training program was successful or just a coincidence. Again, a study with more athletes would probably show more trustworthy results.

It is also difficult to know if there is one type of exercise which is the reason for success since this training program used plyometric, strength training, landing technique and balance. However, strength training performed as in this study, with many different types of qualities being trained, has beneficial results with increased strength and less injury. Therefore it should be a natural part of each training session among adolescent alpine competitive skiers. If only two ACL injuries can be prevented with something as simple as bodyweight strength training, it is already worth it.

5. Conclusion

Adolescents increase in strength without training because of puberty and growing, therefore significant results are limited. However, the TG increased strength significant in the hamstrings, which is an important factor in preventing ACL injuries. Additionally, the CG had three knee injuries during the intervention while the TG had none, also suggesting that the training program was successful.
References


Name:________________________________________________

Female
Male

Birthdate:___________________________________________

Period Since when: _____________
No period

Height: _______cm              Weight:_________kg

Are you in good health at the moment?_____________________________________________________

Asthma:____________________________________________________________________________

Allergy:_____________________________________________________________________________

Heart problems:_____________________________________________________________________

High bloodpressure:__________________________________________________________________

Diabetes:___________________________________________________________________________

Other illness:_______________________________________________________________________

Medicine:___________________________________________________________________________

Nutrition supplement (Vitamin, Minerals, Protein):
__________________________________________________________________________________

Tobacco:   YES     NO     Tried it If YES, what? ________________________________

Alcohol:   YES     NO     Tried If YES, what? ________________________________

Earlier injuries (Back, knee, feet, brain concussion):
__________________________________________________________________________________

Training hours per week in school:_______________________________________________

Sports during your free time:_____________________________________________________

Training hours per week on your free time:________________________________________

➤ I accept that this information is being used in science.
➤ I can at any time and without special reasons quit the intervention.

Signature from athlete:_______________________________     Date: _______________________

Signature from parent: _______________________________    Date:________________________
Appendix 2

Name: __________________________________ Birthdate: __________________________

Date of injury: ____________________________ Race  Ski training  Physical training

What is injured: (Hand, Knee, Foot, Hip, Head etc.):
__________________________________________________________________________________

How did it happen:
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________

What kind of injury (muscle-, ligament rupture, contusion, fracture.):
__________________________________________________________________________________
__________________________________________________________________________________

How serious is the injury (1= can train 2= can not train for one or two days, 3= can not train for one week, 4= can not train for two weeks, 5= can not train for more than 28 days 6= can not train for half of a year or more):  
1. 2. 3. 4. 5. 6.

Medical examination

Doctors’ diagnosis:
__________________________________________________________________________________
__________________________________________________________________________________

Treatment: (rest, medicine, physiotherapy etc.):
__________________________________________________________________________________
__________________________________________________________________________________

Medicine:
__________________________________________________________________________________
__________________________________________________________________________________

Physiotherapy:
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
Training for knee stability phase 1 (week 27-34)

**Warm up:** Run for about 5 minutes in circles, change lap and do exercises (touch the floor, jump high, skip, high knees, kick back)

**Station 1:** Telemark with arms on the hips or stick behind the back. Keep core stability, proud posture, 90 degrees in knee and hip, knee over toe. “fall” forward, do not let the knee wobble, put pressure on the heel and return to start position.

**Station 2:** Hamstrings, one leg hip rise. Keep core stability, arms over chest, shoulders on the ground, knee joint 90 degrees, while the other leg is straight. Press the bum upwards until the body is straight; go slowly back to start position. Keep core stability the whole time and tense the gluteus.

**Station 3:** Straight sit-ups. Keep the lower back in contact with the ground, move upper back slowly up and down, let the stomach work. The lower back may not leave the ground.

**Station 4:** Balance. Stand on one leg and throw medicine ball to each other (2kg).

**Station 5:** Squats with bum touching a bench. Feet little wider than shoulders, knee over feet, look forward, strong core. Bend to 90 degrees and return to start position.

**Total:** 30 minutes
Training for knee stability phase 2(week 34-40)

**Warm up:** Run for about 5 minutes in circles, change lap and do exercises (touch the floor, jump high, skip, high knees, kick back)

**Station 1:** Telemark steps with weight pending from side to side. Hold the weight as a steering wheel. Think about 90 degrees in the knee, straight upper body, look forward, weight on the heel and a strong core. Weight is being moved at the lower position, NOT before. Walk forward and change leg.

**Station 2:** Hamstring on Swiss ball with both feet. Keep the hips parallel and high. Always press the hips towards the sky. Tense stomach and bum. Stretch the legs and then bend the knees, repeat.

**Station 3:** Biking for the abs. The lower back touches the floor. Tense stomach and try to relax the neck. Have both legs in 90 degrees and then move on leg in front while to other stays, go back to start position and change leg.

**Station 4:** Stand on one leg with medicine ball (2kg)/weight (5kg) in the hands. Bend over with straight back and one leg stretching backwards, look down and keep shoulders together. Stop when the back is vertical and return to beginning.

**Station 5:** One leg squat. Bend your knee with control. The knee should go over the foot and not wobble. Stop when you cannot keep the upper body straight or when the heel leaves the ground. Return to start position.

Total: 30 minutes
Training for knee stability phase 3 (week 41-47)

Warm up: Run for about 5 minutes in circles, change lap and do exercises (touch the floor, jump high, skip, high knees, kick back)

Station 1: Telemark steps backwards, advance with weight over head. Stand shoulder width with your feet and move one leg backwards with toes on the ground. Lower your body so you have 90 degrees in both knee joints. Activate your front leg to return to start position. It is important to press with the heel in a powerful movement upwards and at the same time stay stable in knees and hips.

Station 2: Nordic hamstring, work in pairs. One stands behind the other and stabilize the feet. The other slowly falls forward, in control until it is almost not possible to return, and return to start position.

Station 3: Swiss knife for the abs. Lie on the back with good core stability, lower back pressed to the ground. One leg/foot can be on the ground or in 90 degrees, while the other is stretched in the air. The arms are also stretched and meet the foot in the air. Repeat and change leg every second time.

Station 4: Ice-skating with hands on the hips. Jump from side to side, NOT forward. Make a soft landing and have control over the knees position. Keep a strong core and proud body posture.

Station 5: Swiss ball balancing with one leg on the ball. Lie on your back with both feet on the Swiss ball. Tense your whole body and keep the hips in a high vertical position. Make sure you are in balance and move one leg off the ball and lower it towards the ground. Then move leg straight up and repeat. Change leg after 30sec!

Total: 30 minutes
Training for knee stability phase 4 (week 47-1)

**Warm up:** Run for about 5 minutes in circles, change lap and do exercises (touch the floor, jump high, skip, high knees, kick back)

**Station 1:** Jumping telemark with hands on hips. Proud posture, explosive telemarks. Make sure your knee is over the feet, both when landing and taking off=

**Station 2:** Deadlift with light weight bar. Stand shoulder width with the bar hanging in your hands. Have the weight on your heels and tense your stomach. Make sure you have a proud posture and press your bum back, so there is a triangle between your hips and arms. The arms are still hanging, but your shoulders are pressed together. Return to start position by pressing the hips forward.

**Station 3:** Sit ups with bar. Hold the bar shoulder width. Start by stretching arms and legs, keep a strong core. Fold yourself and take the bar over your feet, under the legs and towards the bum. Return to start position.

**Station 4:** Side bridge with leg rise. Lie on the side with elbow and foot/knee on the ground, the other arm resting on your body. Make sure you are completely straight and have a strong core. Stretch the upper leg maximum 50cm upwards and then return to start position.

**Station 5:** Squat with weight. Stand a bit wider than shoulder width with the bar on your shoulders/neck. The feet can point straight ahead or a bit “out”. Bend your knees with control, keep an upright/proud position of the upper body. Go as far down as you can. The heels are not allowed to leave the ground and the upper body has to be straight. Return to first position in an explosive movement.

**Total:** 30 minutes
Training for knee stability phase 5 (week 2-8)

**Warm up:** Run for about 5 minutes in circles, change lap and do exercises (touch the floor, jump high, skip, high knees, kick back)

**Station 1:** Telemark standing on a step board, arms pending. Put one feet on the box and step up, the other leg with 90 degrees in hip and knee joint. Take a step down with the free leg, toes on ground. Make sure the knee does not wobble and that there is 90 degrees in the knee joint, in both legs. Keep a strong core.

**Station 2:** Explosive hamstrings. The help person rolls down the medicine ball on the training person’s thighs and calves. When the ball reaches the Achilles tendon, the training person contracts the hamstrings and the ball is shot to the help person. Repeat!

**Station 3:** Stand shoulder width with the hands and keep a strong straight body. Pull the knees towards the breast and then return to start position in a controlled movement.

**Station 4:** Jump on one leg, back and forth (ca 70cm). Make sure your knee does not wobble and keep a proud posture.

**Station 5:** Side squat with weight. Hold a weight (5kg) with both hands as a wheel and stand with legs far separate. Bend one leg to the side, the other is straight. The upper body is also straight and strong. Return to start position and change side.

**Total:** 30 minutes
Training for knee stability phase 6 (week 9-13)

Warm up: Run for about 5 minutes in circles, change lap and do exercises (touch the floor, jump high, skip, high knees, kick back)

Station 1: Telemark standing on a bench with one foot. The other foot is in front of the bench and hands on the hips. Bend the front leg to 90 degrees in the knee joint, without wobbling with the knee. Return to first position by stretching the front leg. Keep a proud up right position.

Station 2: Explosive hamstring. Lie on your back with one foot on the ground, 90 degrees in knee joint. The other leg is straight in the air. Press your hip up and keep a strong core while you shoot yourself up. Change leg in the air so you land on the other foot, repeat.

Station 3: diagonal sit ups with foot on the opposite knee. Have hand behind the neck and touch left knee with right elbow. Change leg/side after 30 sec. Keep lower back on the ground and relax your neck.

Station 4: Stand stable with both feet on the ground. Bend to 90 degrees in both knees and then jump straight up and turn 180 degrees in the air. Land on both feet again with knees over the feet and a strong core.

Station 5: explosive squat with weight in one hand. Stand stable and tense your core, bend the knees with control, feet over the knees without wobbling. Bend to 90 degrees and return fast to the start position. The arm with the weight is always leaning against the breast.

Total: 30 minutes

* All pictures in appendix 3 are retrieved from  http://www.styrkeprogrammet.se/ovningsarkiv/