

# Neuromuscular Training for Prevention of Anterior Cruciate Ligament Injury in Female Athletes

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## KEY POINTS

- ▶ The prevention of anterior cruciate ligament injury in female athletes through neuromuscular training is explored.
- ▶ Neuromuscular training can increase hamstring muscle strength and improve knee stability.
- ▶ The program design and exercise intensity of neuromuscular training must be revised for female athletes.

Anterior cruciate ligament (ACL) injury occurs often in athletes. The ACL can become twisted during rapid deceleration and sudden cutting, leading to ACL tears or ruptures.<sup>1</sup> ACL injury is four to six times more common among female athletes than among male athletes.<sup>2</sup> These sex differences indicate

that female athletes are more likely to experience ACL injury during high-intensity exercise than male athletes are.<sup>3</sup> In the United States, 95,000 people experience ACL injuries each year. Among female athletes with ACL injuries, 70% decide to undergo surgery.<sup>4</sup> One year of rehabilitation is necessary following ACL reconstruction surgery,

which requires a considerable amount of money and time. In addition, only 30% to 50% of athletes are able to return to the field successfully.<sup>3</sup> ACL injury often results in knee osteoarthritis, causing knee inflammation and pain that affect athletic performance and

shorten athletic careers.<sup>5</sup> Therefore, athletes must focus on preventing ACL injury.

Anterior knee laxity and lower extremity strength are easier to find in female athletes than in male athletes. Thus, the unstable knee structure that leads to ACL injury is more likely to occur in female athletes during certain activities, particularly landing.<sup>6,7</sup> Strength training for lower extremity muscles must be included in physical training programs for female athletes to improve knee instability and prevent ACL injury.<sup>8</sup> Neuromuscular training is often used in physical training for athletes and in rehabilitation training for athletes with sports injuries.<sup>9</sup> Neuromuscular control emphasizes the conscious control of the body and the coordination of various special movements to maintain stability, and is used in lower extremity training for preventing ACL injury. Training the hamstring muscles and quadriceps to generate tension through antagonistic movement reduces the risk of ACL injury.<sup>10</sup> Female athletes lack muscle strength and stability compared with that of male athletes. Therefore, neuromuscular control is a common type of physical training.<sup>6,8</sup> Studies have often investigated the therapeutic effects of

neuromuscular training following ACL injury or ACL reconstruction surgery, reporting that neuromuscular training facilitates postoperative rehabilitation and functional recovery.<sup>9,11</sup> However, relatively few studies have examined the effect of neuromuscular training in preventing ACL injury in female athletes. Therefore, we performed a systematic review on the influence of neuromuscular training on the incidence of ACL injury in female athletes.

## Search and Review of Previous Studies

In this study, we used the electronic journal databases of MEDLINE, PubMed, and CINAHL to obtain the articles on ACL injury and neuromuscular training. We used *knee injury*, *anterior cruciate ligament injury*, and *neuromuscular training* as keywords for this search. The studies were required to meet the following criteria: female athletes were used as research participants, neuromuscular training programs were used to prevent ACL injury, control groups without training were included, ACL injury incidence was used to assess the results, and the study was published internationally between 1995 and 2013. We excluded studies in which sports training was applied after ACL reconstruction surgery in the sample. Finally, two specialists in sports

medicine with more than 10 years of experience selected the articles and compared the content of the studies that met the criteria based on the published year and authors of the article, number of participants, neuromuscular intervention training program, compliance, and results. The analyzed outcome was the incidence of ACL injuries after the athletes received neuromuscular training. We assessed the quality of each study based on the Physiotherapy Evidence Database (PEDro) scale.<sup>12</sup>

## Neuromuscular Training for the Lower Extremities

The initial keyword search resulted in 132 articles. After removing articles based on their abstracts and the expert review, we retained five studies.<sup>13-17</sup> Table 1 shows that the PEDro scores of these five articles were between 6 and 9. The five articles all involved the use of various neuromuscular training programs. Hewett et al used a jump training program that included 60 minutes to 90 minutes of flexibility training, plyometrics, weight training, and stretching three times a week for six weeks.<sup>13</sup> This program emphasized increasing hamstring muscle strength to reduce landing force and increasing lower extremity stability upon landing.

**TABLE 1. DESCRIPTION AND INTERVENTION OF REVIEWED ARTICLES**

Author (years)	Groups (subjects; season)	Intervention	PEDro
Hewett et al (1999) <sup>13</sup>	Intervention group (n = 366; NA) Control group (n = 897; NA)	Jump training program	7
Myklebust et al (2003) <sup>14</sup>	Intervention group (n = 855; 1999–2000) Intervention group (n = 850; 2000–2001) Control group (n = 942; 1998–1999)	Circuit of floor, wobble board, balance mat exercises	8
Mandelbaum et al (2005) <sup>15</sup>	Intervention group (n = 1,041; 2000) Control group (n = 1,905; 2000) Intervention group (n = 844; 2001) Control group (n = 1,913; 2001)	Warm-up, stretches, strengthening, plyometric exercise, and soccer-specific agility drills	8
Petersen et al (2005) <sup>16</sup>	Intervention group (n = 134; 2003) Control group (n = 142; 2003)	Balance board and jump exercise program	6
Gilchrist et al (2008) <sup>17</sup>	Intervention group (n = 583; 2002) Control group (n = 852; 2002)	Warm-up, stretching, strengthening, plyometrics, and sport-specific agility exercises	9

NA = not applicable.

Myklebust et al used a program comprising 15 minutes of three balance exercises performed three times a week for eight weeks. The athletes switched exercises every five minutes. The first seven weeks of training were conducted before the competition season and the eighth week of training was during the competition season.<sup>14</sup> This program emphasized changing landing techniques to increase proprioception, changing landing style through neuromuscular training, and reducing the effects of ground reaction force on the knees. Mandelbaum et al used 20 minutes of warm-up before training. The training comprised stretches, strength training, plyometrics, and special soccer skills training.<sup>15</sup> Petersen et al created a six-stage training program that included balance-board exercises and jump exercises. The athletes performed this program three times a week for eight weeks before the competition season.<sup>16</sup> Gilchrist et al combined stretching, strengthening, plyometrics, and sport-specific agility exercises to form a training module called Prevent Injury and Enhance Performance. The athletes used this module for 12 weeks.<sup>17</sup>

## Incidences of ACL Injury After Neuromuscular Training

The results of these five articles indicated that 4,673 athletes received neuromuscular training and 6,651 athletes who comprised the control groups did not. Table 2 shows that compliance for the five programs of neuromuscular training was between 42 % and 100 %. The groups that received neuromuscular training exhibited a lower incidence of ACL injury than did the control groups in all five articles.<sup>13-17</sup> Figure 1 shows that the incidences of ACL injury for the groups that

received neuromuscular training was between 0.04 ACL injuries per 1,000 athlete-exposures and 0.13 ACL injuries per 1,000 athlete-exposures. The incidence in the control groups was between 0.14 ACL injuries per 1,000 athlete-exposures and 0.51 ACL injuries per 1,000 athlete-exposures.<sup>13-17</sup> The incidence of ACL injury was statistically significantly lower in the groups that received neuromuscular training compared with that in the control groups in both the Hewett et al and Mandelbaum et al studies ( $P < .05$ ).<sup>13,15</sup> Mandelbaum et al analyzed athletes over two seasons and indicated that the incidence of ACL injury during both seasons was statistically significantly lower in the group that received neuromuscular training compared with that in the control groups ( $P < .05$ ).<sup>15</sup> Myklebust et al divided amateur athletes and elite athletes into separate groups when analyzing the incidence of ACL injury and reported that the incidence of ACL injuries was statistically significantly lower in the group of professional athletes who received neuromuscular training compared with that in the control group ( $P < .05$ ).<sup>14</sup>

## Discussion

### Effects of Neuromuscular Training

Previous studies have indicated that neuromuscular training can improve joint position sense, stability, and protective reflexes, thereby preventing ACL injury.<sup>9</sup> Noyes and Barber-Westin stated that neuromuscular training can prevent ACL injury in female athletes effectively. This is consistent with our results.<sup>11</sup> The five articles we examined involved the use of plyometric exercises, jump training, agility exercises, and board exercises for neuromuscular training.<sup>13-17</sup> Athletes must perform dynamic and static response actions

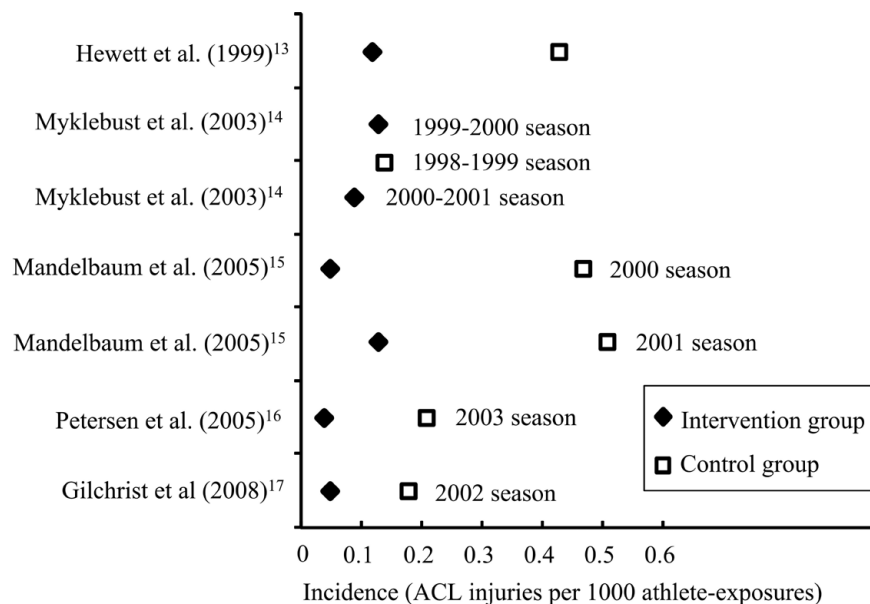
**TABLE 2. COMPLIANCE AND RESULTS OF REVIEWED ARTICLES**

Author (years)	Compliance (season)	Results <sup>a</sup>
Hewett et al (1999) <sup>13</sup>	70 % (NA)	Intervention group > control group
Myklebust et al (2003) <sup>14</sup>	42 % (1999–2000) 50 % (2000–2001)	Intervention group > control group*
Mandelbaum et al (2005) <sup>15</sup>	96 % (2000) 100 % (2001)	Intervention group > control group*
Petersen et al (2005) <sup>16</sup>	99 % (2003)	Intervention group > control group
Gilchrist et al (2008) <sup>17</sup>	96 % (2002)	Intervention group > control group

NA = not applicable.

<sup>a</sup> Athletes with ACL injuries in the intervention group compared with the control group.

\* $P < .05$ ; intervention group vs. control group.



**Figure 1** The incidence of ACL injury of reviewed articles.

when landing after jumps and decelerating to maintain knee stability.<sup>18</sup> The programs used for neuromuscular training in each of the five articles satisfied athlete requirements for training in the use of dynamic and static response actions. Our analysis indicates that three factors may influence the effectiveness of neuromuscular training in preventing ACL injury. First, strengthening the hamstring muscle groups facilitates knee stability and reduces the incidence of ACL injury. Second, because female quadriceps and hamstring muscles are unbalanced and antagonistic, training in the use of static response actions can improve the antagonistic contraction capability of muscles. Third, training in the use of dynamic response actions can reduce knee varus and valgus upon landing and increase joint stability against landing stress.

### Compliance and Injury Prevention in Neuromuscular Training

Medina et al examined electromyography changes in the thigh muscles of athletes when landing after jumps. They determined that the hamstring muscle activation in females requires specific neuromuscular training to prevent ACL injury.<sup>19</sup> In this study, we discovered that the five neuromuscular training programs were all capable of reducing the incidence of ACL injuries in female athletes.<sup>13-17</sup> The reviewed literature indicates that neuromuscular training can reduce force peaks upon landing in female athletes.<sup>13,15,16</sup> In addition, the quadriceps and hamstring muscles of female ath-

letes were imbalanced before training. The training improved the strength and explosive power of the hamstring muscles, thereby lending more support to the ACL.<sup>13,15,16</sup> In addition, we compared athlete compliance among the articles. Hewett et al, Petersen et al, and Gilchrist et al indicated that 70% to 99% of the athletes completed their training.<sup>13,16,17</sup> Mandelbaum et al conducted analyses over two years.<sup>15</sup> In the first year, 96.15% of the participants completed the program (2000 season). In the second year, 100% of the participants completed the program (2001 season).<sup>15</sup> Myklebust et al indicated that only 26% of the amateur athletes completed the program in the first year (1999 to 2000 season), whereas 42% of the elite athletes completed the program. In the second year (2000 to 2001 season), 29% of the amateur athletes and 50% of the elite athletes completed the program.<sup>14</sup> Athletes require time to adapt to neuromuscular training. Therefore, when athletes are accustomed to and familiar with the workouts, compliance will increase the following year. Dynamic and static response action training included in neuromuscular training involves particular training exercises and intensities.<sup>20,21</sup> Amateur athletes struggle to adapt to workouts. Revisions to neuromuscular training workouts for the general female population and amateur athletes must be considered in the future.

We analyzed the prevention of ACL injury and determined that the incidence of ACL injury was lower in the groups that received neuromuscular training

than that in the control groups. This indicates that neuromuscular training facilitates the prevention of ACL injury in female athletes.<sup>13-17</sup> Myklebust et al reported an incidence of 0.13 ACL injuries per 1,000 athlete-exposures in the first year and 0.09 ACL injuries per 1,000 athlete-exposures in the second year.<sup>14</sup> This indicates that neuromuscular training was effective in preventing ACL injury despite low compliance. The incidence of ACL injury decreased further as compliance increased.<sup>22</sup>

## Conclusion

Neuromuscular training is effective in preventing ACL injury in female athletes. We recommend conducting specific training in the use of dynamic and static actions. Furthermore, the training program design should consider the involvement of the hamstring muscles. The training program design must be revised, or the exercise intensity must be reduced, for the general female population and amateur athletes to increase compliance and improve the prevention of ACL injuries.

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