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Anterior cruciate ligament injury and ankle dorsiflexion

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Abstract
Purpose The aim was to study whether the degree of ankle dorsiflexion differs between subjects with an anterior cruciate ligament (ACL) injury and uninjured controls. Another aim was to study ankle dorsiflexion between the injured and the uninjured leg and in addition between women and men with an ACL injury.
Method Sixty subjects (ACL injury, $n = 30$ and controls, $n = 30$) were enroled consecutively at two physical therapy settings. Ankle dorsiflexion was measured with a goniometer in a standardized way in a weight-bearing lunge position.
Results Repeated-measures ANOVA revealed a significant difference ($p < 0.001$) in ankle dorsiflexion between subjects with an ACL injury (mean 41.1° SD 5.7) and those without (mean 46.6° SD 5.3). No difference in ankle dorsiflexion was found between the injured leg and the uninjured or between women and men with ACL injury.
Conclusion The present findings suggest lower degree of ankle dorsiflexion in subjects with an ACL injury than in uninjured controls. A functional test measuring ankle dorsiflexion with a goniometer may be one way of identifying individuals at increased risk of ACL injury.
Level of evidence Comparative study, Level II.

Keywords Ankle · ACL injury · Dorsiflexion · Knee · Valgus

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Introduction

Twenty per cent of all sports-related knee injuries involve the anterior cruciate ligament (ACL) [17], and women show a four-to-six-fold greater incidence than men [14]. The highest incidence is reported among basketball, soccer, and handball players [21]. Approximately 70 % of all ACL injuries occur without physical contact [8, 14, 20], during pivoting, deceleration, or landing [8, 14]. About half of those who are injured demonstrate an isolated ACL injury, whilst others may suffer concomitant injuries in menisci, collateral ligaments, and articular cartilage [9, 11, 26].

The causes of non-contact ACL injuries are likely multifactorial, and a combination of external rotation of the tibia and a knee valgus reportedly increases the risk of ACL injury [15]. Less knee flexion and increased knee valgus during landing also create greater vertical forces on the knee joint, which increases ACL loading and thus the risk of injury [8, 15]. Women have a smaller ACL in relation to body weight, with less resistance than men's [2, 13]. Further, women develop a greater knee valgus and greater peak vertical ground reaction force on the knee joint during landing [2, 13]. A valgus position of the knee during a jump-landing task was reported to predict the risk of ACL injury in female athletes [14].

Recent researches studying ACL injuries and biomechanics during landing have focused on knee and hip mobility, with less focus on ankle mobility [8]. Limited ankle dorsiflexion may prevent movement of the knee forward over the foot, resulting in a compensatory displacement of the knee in the frontal plane [19, 24].

Individuals with less ankle dorsiflexion show a greater knee valgus during landing than those with a greater [12, 24]. Also, decreased ankle dorsiflexion reportedly correlates with a lower degree of knee flexion and greater impact on the knee, which may increase the risk of ACL injury [8]. To prevent ACL injury, it is important to find simple diagnostic tools to be used in clinical or sports medicine settings to detect those at increased risk [8].

No study has to date reported whether subjects diagnosed with an ACL injury show less ankle dorsiflexion than uninjured do. The present aim was therefore to investigate whether the degree of ankle dorsiflexion in subjects with an ACL injury differs from that measured in uninjured controls. A further aim was to seek a difference in ankle dorsiflexion between men and women with ACL injury. The hypothesis was that ACL-injured subjects show a lower degree of ankle dorsiflexion than uninjured subjects do.

Materials and methods

Fifteen physical therapists at two physiotherapy settings in Stockholm, Sweden, were informed about the study both orally and in writing and agreed to participate in recruiting subjects.

Subjects

Subjects ($n = 30$) with a primary diagnosis of non-contact ACL injury seeking physical therapy care or scheduled for a check-up following rehabilitation, plus voluntary controls ($n = 30$) without ACL injury, were included consecutively. The controls were patients seeking care for other disorders than knee pain on one of the two settings ($n = 30$). They were matched with those in the ACL group regarding sex and age (±1 year). All enrolled subjects ($n = 60$) gave their written consent after oral and written information.

Inclusion criteria were men and women with a non-contact ACL injury verified by MRI or arthroscopy with an injury no less than 6 months and no more than 5 years previously and aged 16–40 years. The ACL reconstruction had to be performed at least 6 months prior to the test session. Exclusion criteria were ACL injuries due to alpine skiing (the ankle dorsiflexion is restricted in the boot) or any other ankle joint dysfunction and/or ankle sprain that had occurred less than 12 months prior to the test session. Uninjured controls with any ankle joint dysfunction and/or ankle sprain that occurred less than the previous 12 months, and those who had undergone knee surgery for reasons other than ACL injury less than 6 months previously, were excluded (Table 1).

Table 1 Demographic data for subjects with ACL injury ($n = 30$) and uninjured controls ($n = 30$) presented with mean and SD

	ACL ($n = 30$)	Uninjured controls ($n = 30$)
Age (year)	24.9 (6.5)	24.8 (6.6)
Sex (women/men)	15/15	15/15
Height (cm)	175.8 (8.0)	174.3 (8.9)
Weight (kg)	74.1 (13.5)	69.0 (10.3)
Subjects with a unilateral ACL injury (n)	27	–
Subjects with bilateral ACL injury (n)	3	–
Months since injury	22.9 (15.1)	–
Subjects with an ACL reconstruction (n)	30	–

ACL anterior cruciate ligament, *SD* standard deviation

Procedures

Data was collected by one rater (a physical therapist) by measuring ankle dorsiflexion with a goniometer in a standardized way. Measurement was preceded by a 10-min warm-up at a speed of 60 RPM on an ergometer bicycle (Johnson C 7000). Before warm-up, all subjects completed a questionnaire on demographic data such as age, sex, height, weight, and employment, as well as activity level. The subjects with an ACL injury were also asked about injury date and mechanism and date of ACL reconstructive surgery.

Goniometric measurement

The starting position for the goniometric measurement was standardized, with the subject standing in a weight-bearing lunge position with the foot to be measured positioned on a spot marked with tape on the floor and with the other foot behind. To measure the ankle dorsiflexion, the subject was instructed to actively move the front knee forward over the foot towards a mark on the wall in order to avoid deviation of the knee (Fig. 1). The position of the goniometer was standardized so that its solid arm was aligned with the floor and the mobile arm was in line with the fibula, marked with a line for this purpose. The task was monitored by the rater who palpated the heel during the knee movement to ensure contact with the floor throughout the movement. The rater read the goniometer when end position of the ankle dorsiflexion was reached and the measurement (degrees) was registered on a paper chart. The order of measurement of the right and left ankle was randomized by drawing a note marked "right" or "left" from an envelope with 100 notes marked "right" or "left". Ankle dorsiflexion was measured bilaterally, and the value for each ankle and the composite

Fig. 1 Standardized measurement of ankle dorsiflexion with a goniometer

mean value (average of right and left foot) were calculated for each subject.

The reliability of goniometric measurement of ankle dorsiflexion in weight-bearing positions is reportedly very good (ICC 0.85–0.96) [16]. For the present study, an intra-rater reliability test of the goniometric measurement performed for the first nine subjects in each group showed almost perfect reliability (ICC = 0.97). The test–retest measurements were performed by letting the subject step out of, and after a few minutes once again into, the starting position.

Ethics

All subjects asked to participate in the study gave their written consent following verbal and written information. The study followed the Helsinki declaration, and enrolled subjects were informed that they could terminate their participation at any time without implications for further treatment. The study was approved by the Ethical Board at Karolinska Institutet (Registration number 2013/362-31/1).

Statistical analysis

A power calculation performed to reach an alpha power of 0.8 and $p < 0.05$ required at least 30 subjects (15 subjects per group). For adequate study of subgroups of men and women with an ACL injury, 60 subjects were enroled. The power analysis was calculated on a difference in ankle dorsiflexion of 4.8°, based on results previously reported where low ankle dorsiflexion increased the risk of developing patellar tendinopathy [3].

Demographic data are presented with mean and standard deviations (SD) in tables for all variables.

A general linear model (GLM) of repeated-measures analysis of variance (ANOVA) was used to evaluate the within-group and between-group effect of degree of ankle dorsiflexion on (1) subjects with an ACL-injured leg/uninjured leg and (2) uninjured controls' left and right legs, respectively. The data were screened for normal distribution.

Student's independent *t* test was in addition used to describe the difference in ankle dorsiflexion between men ($n = 15$) and women ($n = 15$) with an ACL injury. When comparing men and women in the ACL group, the average ankle dorsiflexion of the right and left ankle of each subject was calculated.

The significance level was set to $p < 0.05$. All analyses were performed with Statistical 10.0.

Results

No subject asked to participate in the study declined. All subjects with an ACL injury ($n = 30$) had undergone reconstructive surgery. Three of the 30 subjects had bilateral ACL injuries (10 %). Mean time from surgery was 22.9 (SD 15.1) months.

The data were normally distributed. A repeated-measures GLM ANOVA showed a main overall effect of significantly lower ankle dorsiflexion in the group with an ACL injury than in the uninjured controls ($F_{1.55} = 13.0$; $p < 0.001$). Mean ankle dorsiflexion in the ACL group was 41.1° (SD 5.7) and in the control group 46.6° (SD 5.3) (Table 2, Fig. 2).

Among the subjects with an ACL injury in only one leg ($n = 27$), the mean ankle dorsiflexion of the injured leg was 41.2° (SD 6.2), which did not differ significantly from that of the uninjured leg 41.3° (SD 6.1).

No significant difference in ankle dorsiflexion was found between men and women with an ACL injury. The average ankle dorsiflexion in women was 40.9° (SD 5.3) and in men 41.3° (SD 6.2).

Discussion

The present aim was to compare degree of ankle dorsiflexion in subjects with an ACL injury with that in age- and gender-matched subjects without injury.

Table 2 Ankle dorsiflexion (°) in subjects with ACL injury ($n = 30$) and uninjured controls ($n = 30$), presented with mean and SD

	ACL ($n = 30$)	Uninjured controls ($n = 30$)	p
Ankle dorsiflexion both legs	41.1 (5.7)	46.6 (5.3)	<0.001
Ankle dorsiflexion ACL-injured leg ($n = 27$)	41.2 (6.2)		ns
Ankle dorsiflexion ACL uninjured leg ($n = 27$)	41.3 (6.1)		
Ankle dorsiflexion left leg uninjured controls		47.2 (5.1)	ns
Ankle dorsiflexion right leg uninjured controls		46.1 (5.7)	
Ankle dorsiflexion ACL men ($n = 15$)	40.9 (5.9)		ns
Ankle dorsiflexion ACL women ($n = 15$)	41.3 (6.7)		

ACL anterior cruciate ligament, *SD* standard deviation, *ns* non-significant

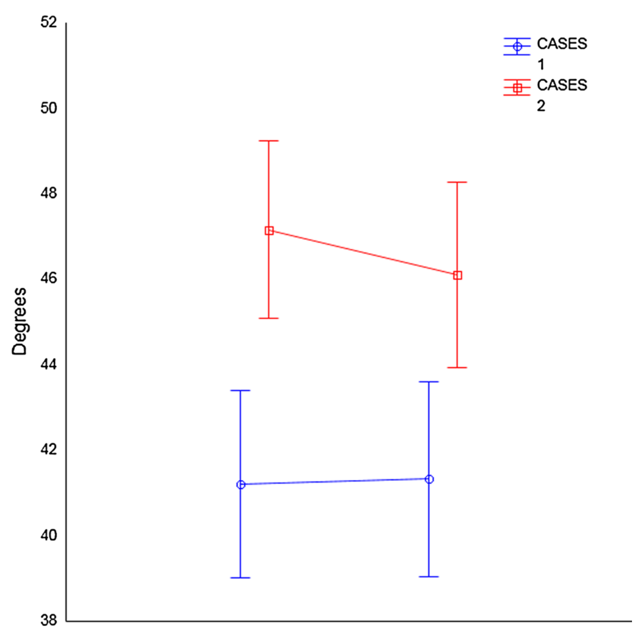

Fig. 2 Ankle dorsiflexion in *1* subjects with ACL injury (injured leg/uninjured leg) and *2* uninjured controls presented with mean and 95 % confidence intervals. ***$p < 0.001$

Average ankle dorsiflexion in those with an ACL injury was significantly lower than in the uninjured controls ($p < 0.001$). Further, no significant difference in ankle dorsiflexion was found between the injured leg and the uninjured leg, or between women and men with an ACL injury.

To our knowledge, no study has to date reported on ankle dorsiflexion in subjects with an ACL injury and compared this to subjects without such an injury. Ankle dorsiflexion has, however, been studied in relation to other knee dysfunctions such as patella tendinopathy, basketball players with less ankle dorsiflexion (<36.5°), showing a higher risk of developing patella tendinopathy than those with greater dorsiflexion [3]. Another study reported limited ankle dorsiflexion measured through decreased flexibility of the gastrocnemius muscle in subjects with femuropatellar pain compared to healthy subjects [26]. However, contradictory results were reported [22] in 16–18-year-old subjects with femuropatellar pain who showed greater passive ankle dorsiflexion than healthy subjects. One reason for these contradictory results may be differing measurement procedures, making it difficult to compare results between studies.

The present results' study suggests that limited ankle dorsiflexion might increase the valgus position of the knee and thus increase the risk of ACL injury. Several authors have studied the role of ankle dorsiflexion with regard to load and biomechanics in the knee joint [4, 7, 8, 19]. In one study, ankle dorsiflexion was restricted with a wedge whilst the subject performed a double-legged squat [18]. This was compared to squatting without restriction and resulted in a lower level of knee flexion, an increased knee valgus, reduced quadriceps activation electromyography (EMG), and increased soleus activation (EMG) [19]. Further, Devita and Skelly [7] demonstrated that the muscular system absorbs 19 % more kinetic energy in a softer landing with greater knee flexion, than in a landing with less knee flexion.

No difference in ankle dorsiflexion between men and women with an ACL injury was detected. It is, however, reported that women have a greater tendency to knee valgus than men have [2, 13]. One study [23] compared ankle dorsiflexion in women with or without knee valgus during a step-down test and reported that those with knee valgus showed less ankle dorsiflexion than those who kept their knees stable in the frontal plane [23].

It is suggested that ankle mobility may affect the ability to control the knee in the frontal plane and thus joint load [19]. In the present study, it is not clear whether the reduced ankle dorsiflexion was a contributing factor to the ACL injury or whether the limited dorsiflexion was a result of the ACL injury—a classic chicken-and-egg situation. However, no difference in ankle dorsiflexion was found between injured and uninjured legs, which may indicate that the reduced ankle dorsiflexion was not due to the ACL injury or other previous injuries.

Strength of the present study is that enough subjects were included to reach a good power in the analysis. Based on the power analysis, 15 subjects in each group were enough. Twice as many per group were included ($n = 30$). This was done to be able to analyse the subgroups of men and women. To calculate power, the result of a previous study on ankle dorsiflexion and knee pain was used, and this may be discussed [3]. However, the results of Backman et al. [3] showed significant differences in ankle dorsiflexion as did the present study, so we consider that the present study had a good power.

The use of a goniometer to measure ankle dorsiflexion may be discussed, since the reliability and validity of goniometer measurement reportedly vary. However, Konor et al. [16] compared three different techniques for measuring ankle dorsiflexion in a standing-lunge position: goniometer, distance-to-wall, and digital inclinometer. These techniques all showed good reliability (ICC 0.85–0.99), with a slightly higher reliability for the distance-to-wall and inclinometer techniques. Goniometric measurement of the knee joint has, in addition, previously been validated by comparing it to those of roentgenograms with excellent results ($r = 0.97$–0.98) [10]. One important advantage of measurements with a goniometer is that they are easily performed in clinical settings without the need of other equipment. In addition, the present measurements were obtained in a weight-bearing lunge position, considered to be appropriate. Other studies reporting passively measured ankle mobility in non-weight-bearing positions showed lower reliability than measuring techniques in weight-bearing positions [1, 5, 6, 25]. A bias in the present study is that one rater performed all the measurements, not blinded to whether the subjects were injured or uninjured. A blinded rater is optimal for the results and will be considered for future studies.

Several factors are proposed for an increased risk of injury or re-injury of the ACL. Limited ankle dorsiflexion might be one. It is important to find simple diagnostic tools to be used in both clinical and sports medicine settings to identify subjects with an increased risk. Even if the present study has some limitations, the results indicate a difference in ankle dorsiflexion between injured and uninjured controls. There is of course a need to confirm this in future studies.

Conclusion

The present findings suggest that a lower degree of ankle dorsiflexion is present in subjects with an ACL injury than in uninjured controls. A functional test where ankle dorsiflexion is measured with a goniometer may be one way of identifying individuals at increased risk of ACL injury.

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