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Poor static balance is a risk factor for non-contact anterior cruciate ligament injury

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Abstract

Background This prospective study aimed to investigate the relationship between static balance and the incidence of non-contact anterior cruciate ligament (ACL) injury in female high school athletes.

Methods This study included 276 female high school handball or basketball players. At the time of admission, each subject's static balance was measured with a gravicorder, and the incidence of non-contact ACL injury was investigated in the 3 years until the student graduated. The measured parameters of postural sway were locus length per time (the distance that a center of gravity of the foot pressure moves per second) and environmental area (AR: the area surrounded by the integumentary covering of the trace of the center of gravity). Twenty-seven players (9.8%) experienced an ACL injury during the 3-year observation period. Twenty-four injured players sustained a non-contact injury and three injured players sustained a contact injury. In this study, the three contact injury players were excluded. We compared the differences in the static balance between injured and uninjured players.

Results The locus length per time was significantly longer in injured than in uninjured players ($p = 0.046$). Though there was no statistically significant difference between the two groups in AR ($p = 0.190$), AR tended to be larger in the ACL injured group.

Conclusions This result shows that poor static balance is a risk factor for non-contact ACL injury.

Keywords Female · High school · Handball player · Basketball player · Gravicorder

Introduction

Untreated ACL injury leads to poor outcomes. At a minimum mean follow-up of 10 years, the meta-analysis and systematic review reporting on the outcomes after ACL injury shows the risk of developing osteoarthritis is higher in untreated ACL injuries [2], and the patients who underwent ACL reconstruction had fewer subsequent meniscal injuries, less need for further surgery, and significantly greater improvement in activity level [5]. In young athletes with an ACL injury, ACL reconstruction and more than 6 months of rehabilitation are necessary to allow a return to their sport. From a financial perspective, the direct surgical costs related to ACL injury are nearly 850 million dollars annually [13], with an additional 2 billion dollars of indirect costs for post-surgical care and rehabilitation.

Therefore, in recent years, the focus on ACL injury prevention has increased and many studies exploring risk factors for ACL injury have been published. Women have a 3–8-times greater risk for ACL injury than similarly trained men [30] for many reasons, including non-modifiable (anatomical and hormonal) and modifiable (neuromuscular) risk factors [12, 19]. The increased risk in women is especially prominent in sports that require cutting and landing motions, such as soccer, lacrosse, handball and basketball [1, 9, 23, 27]. Neuromuscular control of the core [3, 13] and

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hip musculature [3, 6, 25] plays an important role in lower extremity mechanics and may influence ACL and lower extremity injury risk.

Balance is defined as the capacity to maintain the projected center of mass within the limits of its supporting base in static or dynamic situations [28]. To measure the balance, we used the gravicoder, which is simple to measure and its effectiveness has been shown [16, 22]. This instrument can measure center of foot pressure (CFP) of vertical loads from the values of the vertical sensors, and calculate the velocity and area of CFP movement. Vrbanic et al. stated that balance was related to the unconscious neuromuscular control and stabilization of the joints [32]. However, there have been no prospective studies of exploring the influence of balance on ACL injuries among female high school players. The purpose of this study was to prospectively investigate the relationship between static balance and the incidence of ACL injury among female high school athletes. We hypothesized that poor balance predisposes an individual to vulnerable knee positions and is the one of the risk factors of non-contact ACL injury.

Materials and methods

Participants

The subjects for this research were 15-year-old high school female athletes ($n = 287$), who were starting participation on the handball team (111 subjects) or the basketball team (176 subjects) from April 2009 to 2011. Subjects with a history of previous lower limb injuries or symptoms were excluded from the study. In total 11 subject were excluded 4 subjects, history of ACL reconstruction; 1 subject, conservative therapy for ACL injury; 1 subject, history of ankle ligament repair; 2 subjects, fresh ankle sprain; 1 subject, stress fracture of tibia; and 2 subjects, history of partial meniscectomy. They participated in teams at the most competitive level of Japanese high schools and practiced 5–6 days per week.

All enrolled subjects were followed for 3 years (276 subjects, 104 handball players and 172 basketball players). In this study, no injury prevention programs were used in any of the team's regular training program.

At baseline, the subject's postural sway was measured for 30 s during two-leg standing with the eyes open using a gravicorder. Anthropometric data (height and weight) were also collected from all players at the time of baseline testing. After the baseline examination was performed at high school entry, all players were followed for 36 months to register any subsequent occurrence of ACL injury.

All coaches were asked to keep a continuous log of all data requested. The coach of each team was contacted by telephone and/or e-mail at least once a month to record new injuries, as well as all playing activities in training and competitions. The definition of ACL injury included cases that were diagnosed in a medical institution after injury through physical and MRI findings and confirmed by direct arthroscopic visualization of a complete ACL rupture during subsequent ACL reconstruction.

We compared the differences in the static balance between the injured and uninjured players.

This study was approved by the ethics committee of Kanazawa University, and written informed consent was voluntarily obtained from the players and their parents after providing a thorough explanation on the content of this research prior to the intervention (approval number: 1050). The voluntary nature of participation was emphasized. The participant consent was recorded as PDF files to the on a password protected computer.

Static balance testing

At baseline, using a gravicorder (Gravicorder GS-31; Anima, Tokyo, Japan), postural sway was measured for 30 s (the sampling period was 40 s and the first 10 s were not included), using a 20-Hz sampling frequency, during two-leg standing with the subject's eyes open.

Balance can be defined as the ability to maintain the body's center of gravity within the base of support with minimal sway. In normal standing, the body's center of gravity refers to a point in the body that is almost equal to the center of gravity of the foot pressure [21]. Therefore, in this study, the body's center of gravity was assumed equivalent to the center of gravity of the foot pressure.

During the testing, the subjects stood barefoot, placing their feet on the center of measurement at a reference point on the examination platform. With their eyes open, the subjects fixed their gaze at a visual point placed 1 m in front of them at eye level so no moving objects could enter their visual field. No preventive device against falling was used (Fig. 1).

The measured parameters of postural sway were locus length per time (LG: the distance that a center of gravity of the foot pressure moves per second) and environmental area (AR: the area surrounded by the integumentary covering of the trace of the center of gravity). LG indicates postural control function by proprioceptive reflexes, and AR indicates the degree of equilibrium impairment [22] (Fig. 2). The parameters, LG and AR, are usually used for examination of dizziness or equilibrium disorder. Recently they are also used in the field of orthopaedics: balance before and after TKA, the balance difference between ACL injured patient and healthy subject [16, 22].

The measurements were carried out two times with a 1-min rest between the measurements. Kitabayashi reported that they carried out three times with same procedure and

Fig. 1 Testing position. The subjects stood barefoot, placing their feet on the center of measurement at a reference point on the examination platform. With their eyes open, the subjects fixed their gaze at a visual point placed 1 m in front of them at eye level so no moving objects could enter the visual field

the intraclass correlation coefficient (ICC) of LG and AR between trial 2 and 3 were 0.97 and 0.93, respectively [17]. Demura measured ten times with 1 min rest for each measurement and showed that there was a significant difference between the first trials and the other trials [8]. Therefore, data from the second measurement were used for analysis in this study.

Statistical analyses

All values are reported in balance parameters as mean ± standard error. We compared the differences in the static balance between injured and uninjured players using the Statistical Package for the Social Sciences (SPSS) for Windows Version 19.0 (SPSS Inc.; Chicago, IL, USA). An unpaired t test was performed to compare the differences in static balance between injured and uninjured players. Values of $p < 0.05$ were considered statistically significant. A prior power analysis for sample size was performed; for an effect size of 0.65, power of 0.80, an α level of 0.05, and an allocation ratio of 0.08; a total of 274 individuals were required.

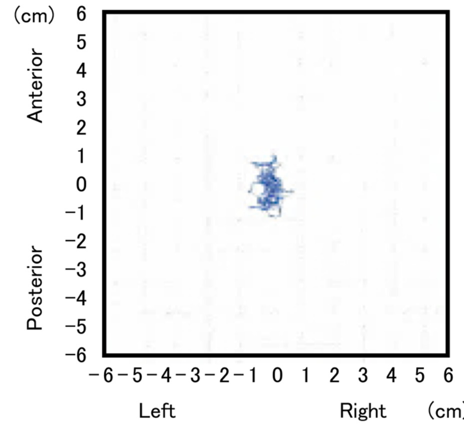

Fig. 2 Representative gravicorder record of the subject (15-year-old female handball player)

Results

In the present study, 27 of the 276 players (9.8%) experienced an ACL injury during the 3-year observation period. Basketball and handball accounted for 15 and 12 players, respectively. Three players experienced contact ACL injury of unilateral knee and 24 players experienced non-contact ACL injury. In this study, three contact-injured players were excluded, because this injury mechanism is related with the direct force to the knee. In 24 non-contact-injured players, 2 players experienced non-contact ACL injury of bilateral knees. In terms of mechanism of injury, 15 knees were injured during a feint, six during landing, and five during other movements. A survey of injury timing showed that many injuries happened when joining a new team or before a major tournament.

There were no differences between the ACL injured group and the uninjured group in physical characteristics such as height and weight (Table 1). The mean values for LG and AR for the two-leg standing with the eyes open test were 1.31 ± 0.37 cm/s and 2.47 ± 1.35 cm^2 in the ACL injured group and 1.15 ± 0.28 cm/s and 2.14 ± 1.19 cm^2 in the uninjured group, respectively. There was a statistically significant difference between the injured group and uninjured group in LG ($p = 0.046$). Though there was no

Table 1 Physical characteristics of subjects

	ACL injured group ($n=24$)	Uninjured group ($n=249$)	p value
Height (cm)	160.6 ± 6.6	161.0 ± 5.7	0.697
Weight (kg)	56.8 ± 6.8	54.9 ± 6.3	0.171

p values were calculated using unpaired *t* test

ACL anterior cruciate ligament

Table 2 Results of static balance test in the ACL injured group and the uninjured group

	ACL injured group ($n=24$)	Uninjured group ($n=249$)	p value
LG (cm/s)	1.31 ± 0.37	1.15 ± 0.28	0.046
AR (cm^2)	2.47 ± 1.35	2.14 ± 1.19	0.190

p values were calculated using unpaired *t* test

LG locus length per time, *AR* environmental area

statistically significant difference between the two groups in AR ($p=0.190$) (Table 2).

Discussion

The most important finding of this study is that the ACL injured group had poor static balance compared with uninjured group prior to the ACL injury. LG, one of the parameters of static balance, measures the speed of movement of the center of gravity, and an increase in LG represents a decrease in postural stability [16, 22]. The LG value of the injured group was significantly higher than that of compared to the uninjured group. Therefore, the ACL injured group had poor static balance compared with in contrast to the uninjured group prior to the ACL injury.

In a study of the use of the static balance test in 2201 normal subjects, the normal LG and AR in women (30 s during two-leg standing with eye open, 20-Hz sampling period) tended to decrease from age of 3 years to the early 20 s. In 15–19.9-year-old girls, the average LG is 1.26 ± 0.31 cm/s, and the average AR is 2.10 ± 1.00 cm^2 [15]. In the present study, the average LG and AR of the ACL injured group was higher than the average of the normal subjects in the above-cited study, while the average of the uninjured group was nearly equal to or lower than the average of the normal subjects in the above-cited study. The average of the normal subjects in that study may serve as a reference.

The reported parameters affecting static balance reportedly include trunk and foot musculature and sensory perception of the bottom of the foot [15, 28]. Training to improve these parameters improves static balance. Trunk exercises have specific training effects that enhance static balance [14], and unstable training devices such as wobble boards enhance proprioception, improve muscle coordination, and strengthen foot muscles, ultimately improving static balance [11, 20, 33, 34].

There are some reports stating that a warm-up program, including balance training, reduces ACL injuries [7, 24, 26]. Olsen et al. reported that 3 out of 958 male and female handball players performing the a 20 min preventive warm-up program, including balance mat and wobble board training, experienced a knee ligament injury during the season, while 14 out of 879 athletes not performing the program experienced a knee ligament injury ($p=0.01$) [24]. Petersen et al. also reported the results of performing a preventive program including wobble board training for female handball players. An ACL injury occurred in 0.04 cases per 1000 play hours in the intervention group ($n=134$), and in 0.21 cases per 1000 play hours in the non-intervention group ($n=142$) [26]. They suggested that balance training is appropriate for the prevention of knee injuries. The results of the present study support previous studies that suggest that balance training is effective for the prevention of non-contact ACL injury.

LG indicates postural control function by proprioceptive reflexes [16, 22]. There was a statistically significant difference in LG ($p=0.046$) between the ACL injury and noninjury groups. However, this result does not mean that it is possible to prevent ACL injury by reflexively correcting a vulnerable knee position. Dyhre-Poulsen et al. stimulated the sensory nerve fibers inside the ACL electrically and elicited a muscular contraction of the semitendinosus muscle, which lessens the strain on the ACL [10]. Solomonow et al. showed that this reflex contributes to the sensorimotor control of the knee [31]. It is known that ACL strain reaches a peak that corresponds to the peak ground-reaction force [4], and Koga showed that the mean peak vertical ground-reaction force was 3.2 times the body weight and occurred at 40 ms after initial contact with the ground using three-dimensional video analyses of an ACL injury [18]. On the other hand, the latency between ACL stimulation and the hamstring response was 95 ± 35 ms with the knee in a relaxed position, but the latency was 65 ± 20 ms during isometric contraction of either the extensor or the flexor muscles [10]. Furthermore, it takes 40 ms to generate enough tension to prevent injury or to stabilize the knee after electrical stimulation of the hamstring [35]. Therefore, the ligament-muscle reflex is too late for the prevention of ACL rupture.

Trunk and toe muscular strength and sensory perception of the bottom of the foot influence static balance ability, and improvement of these leads to improvement in static balance [14, 29]. As previously stated, it is impossible to prevent ACL injury by reflexively correcting a vulnerable knee position. Therefore, an improvement of static balance ability does not increase the speed of the ligament-muscle reflex, but enhances the ability of the individual to avoid vulnerable knee positions, in particular knee valgus, that lead to ACL rupture.

A limitation of this study was that we only investigated LG and AR in our evaluation of static balance. There are many methods for investigating static balance and the optimal method is not apparent. The other limitation was that we did not investigate the scores which might change during the period such as growth spurt, other injuries, and diet. Moreover, we did no intervention and did not investigate whether balance training improves static balance and reduces the occurrence of ACL injury. These are areas for future investigation. However, static balance in the ACL injury group was obviously poor and we believe that balance training is effective for the prevention of ACL injury.

There are many risk factors for non-contact ACL injury and this study demonstrates that poor static balance is a contributing factor to non-contact ACL injury.

Conclusion

In the present study, locus length per time was significantly longer in injured players compared with uninjured players. This result demonstrates that the poor static balance is a risk factor for non-contact ACL injury. Balance training may be effective in ACL injury prevention.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the ethics committee of Kanazawa University (approval number: 1050).

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