J Physiol Sci (2015) 65:165–170
DOI 10.1007/s12576-015-0355-x

ORIGINAL PAPER

Gender difference in distance of tibiofibular syndesmosis to joint dynamics of lower extremities during squat

Michie Okazaki · Masaaki Kaneko · Yukisato Ishida · Norio Murase · Toshihito Katsumura

Received: 27 November 2014 / Accepted: 2 January 2015 / Published online: 24 January 2015

Abstract The incidence of lower extremity injury is greater in women than men, indicating gender difference in lower extremity function. Here we investigate the role of the ankle during squatting in young men and women by measuring the tibiofibular syndesmosis (TFS) distance and the angles of hip, ankle and knee joints. TFS distance was positively correlated to body mass in men, but not in women, suggesting some factor(s) affecting TSF distance in women. When divided into two groups with wide and narrow TFS distances, men apparently used ankle and hip joints evenly during squatting, but women, specifically those with a narrow TFS distance, used the hip joint more effectively than ankle. Estimated knee moment was positively correlated to TFS distance in women, but not in men. These results suggest that the women possessing a wider TFS distance use ankle function rather than hip junction when performing lower-extremity exercises (i.e. squatting), presumably accounting for the higher incidence of ankle injury in women during such activities.

Keywords Tibiofibular syndesmosis · Ankle instability · Gender difference · Lower extremity injury

M. Okazaki (✉) · N. Murase · T. Katsumura
Course of Medical Science in Graduate School of Tokyo Medical University, 6-1-1 Shinjuku, Shinjuku-ku, Tokyo 160-8402, Japan
e-mail: michie.o@f4.dion.ne.jp

M. Okazaki · Y. Ishida
Department of Physical Therapy, Bunkyo Gakuin University, 1196 Kamekubo, Fujimino-shi, Saitama 356-8533, Japan

M. Kaneko
Department of Rehabilitation, Tohoku University Hospital, 1-1 Seiryo-machi, Aoba-ku, Sendai City, Miyagi 980-8574, Japan

Introduction

Ligament injuries of ankle joint are common during daily life and sports activities [1, 2]. Functional instability of the ankle often occurs in people with a history of ligament injury of the ankle joint [2, 3], resulting in poorer physical performance [4, 5]. Laxity and instability of the joint are often the original causes of the athletic injury and, consequently, worsening athletic ability. The talocrural joint consists of the talus, which fits into the sulcus of the joint cavity of the intercondylar fossa that has a strong association with the distal tibia and fibula [6]. The talocrurual joint is stabilized by this bone structure with the support of the interosseous membrane of the syndesmosis, uniting the anterior inferior tibiofibular ligament, the posterior inferior tibiofibular ligament, the interosseous ligament and the transverse ligament [7–11]. The syndesmosis allows the talocrural joint to move a few millimeters during loading [12], and the ligaments stabilize the joint so as to make a close contact of tibia and fibula [6]. Dysfunction in tibiofibular syndesmosis (TFS) has been reported to profoundly affect ankle ligament injuries caused by the rotation or dilation of fibula [9, 13–15]. TFS is the most serious factor contributing to chronic ankle instability in ankle sprain [16], and the time required to return to sports activities is longer after TFS than after isolated lateral ligament sprains [17]. Furthermore, ankle injury has a serious effect on the TFS. Although women have a higher incidence of lower extremity injury during sports activities than men [18, 19], this gender-associated causal relationship in the incidence TFS injury has not been clarified.

In this study, therefore, we have focused on the distance of TFS in relation to ankle stability and investigated gender difference in terms of TFS distance and joint dynamics of the lower extremities.

Material and methods

Subjects

Twenty healthy young men [age 20.5 ± 1.1 years; height 172.4 ± 6.4 cm; body mass 65.7 ± 9.3 kg; body mass index 22.1 ± 2.8 kg/m^2] and 20 healthy young women (age 20.6 ± 1.0 years; height 161.2 ± 2.8 cm; body mass 54.9 ± 3.4 kg; BMI 21.1 ± 1.2 kg/m^2) participated in this study. Those individuals with a history of knee orthopedic injury and joint hypermobility were excluded from entry into this study, as were those with hypermobility of the joint (based on pre-study examination using the Beighton Hypremobility Score [20]). The subjects read and signed a written consent form, and the study was approved by the ethics committee of the Faculty of Health Science Technology, Bunkyo Gakuin University.

Measurements during the warm-up

The subjects first rested in a chair for 10 min and then were asked to perform static stretching of the rectus femoris and hamstrings as a warming-up. Each subject was asked to maintain a standing position and then bend their trunk forward and flex their knee with the help of their hand in the prone position. Each static stretching was performed three times and held for 30 s each time. Once the warming-up was completed, we measured the TFS distance and lower extremity joint dynamics during squatting.

TFS distance

Using ultrasonography (MyLab25; Hitachi Medical Corp., Tokyo, Japan), we measure the TFS distance with the subject in the erect standing position with 0° dorsal and plantar flexion of ankle. The probe was put on the left anterior inferior tibiofibular ligament and on the long axis view of TFS, and the distance was measured using image analysis software ImageJ (National Institutes of Health, Bethesda, MD). We performed three measurements at each site, and the mean value was regarded as representative. Both male and female subjects were divided into a "wide" and "narrow" distance group depending on whether or not the measured width was wider than the average value.

Single leg squat

The pivoting or "dominant" leg was determined by asking each subject to kick a ball; in all subjects the left leg was the pivoting (supporting) leg. The pivoting leg (left leg) was used for the squat movement since in women there is a tendency for the anterior cruciate ligament (ACL) of the left leg to tear more frequently than that of the right leg [21, 22]. Subjects stood on their left leg and flexed the knee joint as much as possible, but without a load. This action was performed arms folded over the chest to minimize the balancing effects of the upper extremity. The subjects were allowed to practice the squats in this position (folded arms) several times, and then data were collected on three successfully completed squats. Loss of balance, as evidenced by failure to maintain the fold arm position and/or the other foot coming in contact with the floor during the squat, were considered as flawed attempts.

Dynamics of lower extremity

Peak ground reaction force (GRF) during the squat was measured using the AMTI Biomechanics Force Platform model OR6-7 (AMTI, Watertown, MA) at 100 Hz. The joint moment was normalized by the body mass and the height of the subject.

Angles of the hip, knee, and ankle joints during the squats were measured using the Vicon MX three-dimensional (3D) motion analysis system (Vicon Motion Systems, Oxford, UK) at a frequency of 100 Hz, with eight infrared cameras. We conducted the tests after confirming a measurement error of ≤0.7 mm. Infrared reflective markers were affixed to the subject at positions according to the Plug-in-Gait lower body model (Vicon Motion Systems) at 16 places: both the anterior superior and posterior superior iliac spines; the center of both thighs externally; the lateral joint line of both knees; the center of both shanks externally; the lateral malleolus of both ankles; the center of both heels; the head of the second meta-tarsal of both feet. Marker trajectories were filtered with a Woltring low- pass filter and a 20-Hz cut-off frequency. Ground reaction force data were filtered with a fourth-order Butterworth low-pass filter with zero lag and a 6-Hz cut-off frequency. The angles of the hip, knee, and ankle joints in the sagittal plane were calculated using a Plug-in-Biomechanical Modeler (Vicon Motion Systems). The angle of hip flexion or extension was defined as the angle formed between pelvic axis and femoral axis in the sagittal plane, with flexion denoted as "+" and extension denoted as "−". The angle of knee flexion or extension was defined as the angle formed between the femoral axis and shank axis in the sagittal plane, with flexion denoted as "+" and extension denoted as "−". The angle of ankle dorsiflexion or plantar flexion was defined as the angle formed between the foot vector and shank axis in the sagittal plane, with dorsiflexion denoted as "+" and plantar flexion denoted as "−". We calculated the knee moment and the angle of hip flexion or dorsal flexion at flexed knee joint angles of 10°, 20°, 30°, and 40° during performance of the squat.

Statistical analysis

Values for TFS distance and lower extremity joint dynamics during squatting are given as the mean ± standard deviation (SD). Differences between the "wide" and "narrow" distance group in both men and women were analyzed using the two-sample t test ($P < 0.05$). The relation of distance of TFS and knee moment during squatting was analyzed using Pearson's product-moment correlation coefficient ($P < 0.05$). All analyses were conducted using SPSS version 11.0 for Windows (SPSS Inc., Chicago, IL).

Results

TFS distance

Ultrasonography revealed that the TFS distance in our subjects when in the standing position was significantly wider in the men (3.60 ± 0.32 mm; $n = 20$) than in the women (3.24 ± 0.55 mm; $n = 20$), although the distances in women showed a more scattered distribution (see SD value and Fig. 1). When TFS distance was normalized by body mass, all distance values for both men and women seemed to be positively correlated to body mass ($r = 0.47$, $n = 40$, $P < 0.05$). The correlation in men was apparently positive ($r = 0.46$, $n = 20$, $P < 0.05$), although the distribution of TFS distance was relatively restricted when compared to that of the women subjects. In contrast, in women there was no positively significant correlation between body mass and TFS distance ($r = 0.02$, $n = 20$), presumably due to the narrow distribution in body mass of women, which occurred unintentionally. These results suggest that TFS distance in women is affected by some intrinsic factor(s) inherent in women—and not solely to body mass—although these factors are currently unknown.

In comparison, when TFS distance was normalized by body height, TFS distance was positively correlated with body height in all subjects ($r = 0.42$, $n = 40$, $P < 0.05$), but not significantly with height of the group of men ($r = 27$, $n = 20$, $P = 0.243$) or group of women ($r = 0.19$, $n = 20$, $P = 0.423$). These results suggest that height may have some relation to TFS distance, but that the relation with gender might not be strong compared with that of body mass, as described above.

The TFS distance was more widely distributed in women than in men (Fig. 1). Among the 20 female subjects, those with a shorter TFS distance based on the average value seemed to represent the typical female type and the common type equivalent to the male type. Therefore, we further analyzed TFS distances of our male and female subjects by dividing the subjects into "wide" (W; larger TFS distance) and "narrow "(N; smaller TFS distance) TFS distance groups based on mean TFS values (Table 1). In both our male and female subjects, TFS distance in the W group (men 3.9 ± 0.2 mm; women 3.6 ± 0.2 mm) was significantly longer than that in the N group (men 3.4 ± 0.2; women 2.6 ± 0.3 mm) ($P < 0.05$). The ratio of W to N (W/N) was 1.15 in men; in women it was relatively longer, 1.38, due to the small value of the female N group. These results indicate that the difference in TFS distance between the W and N groups is much larger in women than men, in parallel the more widely scattered distribution in TFS distances in women.

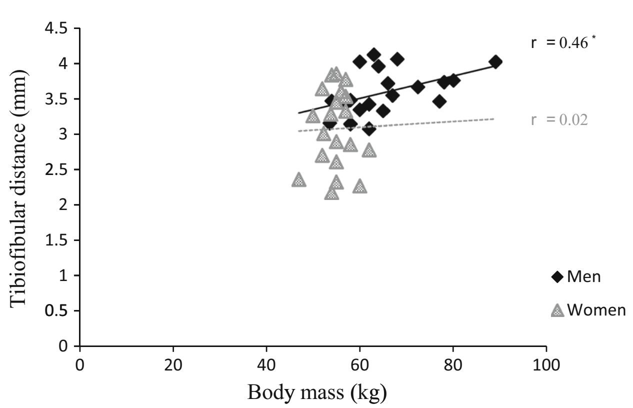

Fig. 1 Relation of tibiofibular syndesmosis (TFS) distance to body mass in men (*filled diamonds*) and women (*gray-colored triangles*) aged approximately 20 years. *Abscissa* and *ordinate* Body mass (kg) and the TFS distance (mm) respectively. Linear regression lines for men (*solid line*) and women (*dotted line*) are shown with $r = 0.46$ for men and $r = 0.02$ for women

Single leg squat

The lower extremity joint dynamics of our male and female subjects assigned to either the W or N group based on TFS distance were examined during the performance of single leg squats by measuring the angles of hip flexion and ankle dorsiflexion at 10°, 20°, 30°, and 40° knee flexion (Table 2). We noted that the angles of hip flexion and ankle dorsiflexion gradually increased in all W and N (both men and women) with increases in knee flexion from 10° to 40°.

The angles of hip flexion and ankle dorsiflexion at each knee flexion angle of 10°–40° were nearly equal in both the W and N groups of men, and in the W group of our female subjects, these angles were comparable with those of men. However, in the N group of our female subjects, the hip flexion angle at each knee flexion angle was significantly larger than those of women in the W group and men in the W and N groups. Interestingly, the dorsiflexion angle of women in the N group was significantly smaller than those of the other groups. It would appear that the ratio of the angle of dorsiflexion to hip flexion was much smaller in the N

Table 1 Tibiofibular syndesmosis distance

Tibiofibular syndesmosis	Men ($n = 20$)		Women ($n = 20$)	
	Wide	Narrow	Wide	Narrow
Tibiofibular syndesmosis distance (mm)	3.9 ± 0.2 ($n = 9$)	3.4 ± 0.2[a] ($n = 11$)	3.6 ± 0.2 ($n = 10$)	2.6 ± 0.3[a] ($n = 10$)

[a] In both the male and female subjects women, the tibiofibular syndesmosis (TFS) distance was significantly longer ($P < 0.05$) in the “wide” (W; TFS distance longer than the mean TFS distance) group than in the “narrow” (N; TFS distance shorted than the mean TFS distance) group

Table 2 Hip flexion and dorsal flexion angles with increases in knee flexion from 10° to 40° during the performance of single leg squats

Flexion	Men		Women	
	Wide	Narrow	Wide	Narrow
10° knee flexion				
Hip flexion (°)	9.4 ± 4.1	11.0 ± 3.6	12.5 ± 6.3	17.4 ± 4.1
Dorsal flexion (°)	10.1 ± 2.3	11.1 ± 2.6	10.3 ± 2.7	7.6 ± 1.0[a]
20° knee flexion				
Hip flexion (°)	15.7 ± 4.7	16.7 ± 3.5	17.6 ± 6.1	23.3 ± 4.3[a]
Dorsal flexion (°)	14.9 ± 2.5	16.3 ± 2.9	15.4 ± 2.5	12.6 ± 1.0[a]
30° knee flexion				
Hip flexion (°)	21.7 ± 5.1	22.3 ± 4.0	22.7 ± 6.4	28.8 ± 4.9[a]
Dorsal flexion (°)	19.7 ± 2.6	21.7 ± 3.0	20.7 ± 2.3	17.8 ± 1.0[a]
40° knee flexion				
Hip flexion (°)	27.9 ± 5.7	28.5 ± 4.6	27.6 ± 6.8	34.4 ± 5.5[a]
Dorsal flexion (°)	24.7 ± 2.7	26.8 ± 2.8	26.1 ± 2.1	23.1 ± 1.1[a]

[a] In women, hip flex angle significantly decreased and dorsal flexion angle significantly increased in the W group compared to the N group ($P < 0.05$)

subgroup of our female subjects (0.40–0.67) than in the other groups (0.82–1.07), although in all women it gradually increased with increases in knee flexion from 10°–40°—but not in men. Since this low ratio might indicate a larger contribution of hip flexion than dorsiflexion to stabilize the squat posture with knee flexion, women in the N group may use more hip flexion than dorsiflexion.

The lower extremity dynamics was further analyzed to gain an understanding of the relation of the calculated knee moment to TFS distance at knee flexion angles of 10°, 20°, 30° and 40° during squatting (Fig. 2). In our female subjects, there was a significant positive correlation between TFS distance and knee moment ($r = 0.51$, 0.54. 0.56, and 0.57 at knew flexion angles of 10°, 20°, 30° and 40°, respectively) ($P < 0.05$); this significant correlation was not present in our male subjects ($r = -0.03$ to 0.18). Based on these results, we suggest that the knee moment during squatting increases with longer TFS distance in women, but not in men.

Discussion

In our study we focused on whether or not there are gender differences in terms of TFS distance and joint dynamics of the lower extremities during squat exercise. Since the TFS links the tibia and fibula, the length of the TFS (distance) may play a role in ankle stability. It has been reported that widening of the ankle mortise joint by as little as 1 mm reduces the contact area of the tibiotalar joint by 42 % [23]. Our experiments revealed that the TFS distance was generally longer in our male subjects than in our female subjects. However, the dynamics of the lower extremities during squats at a knee flexion angle of up to 40° were different in the genders. Our male subjects with either a longer or a shorter TFS distance appeared to use both hip flexion and ankle dorsiflexion evenly. In contrast, among our female subjects the hip flexion angle was bigger than the dorsiflexion angle during the squat movement. More specifically, those women with a shorter TFS distance performed the squat exercise with significantly bigger hip flexion and smaller dorsiflexion. Thus, it would appear that specifically those women with a shorter TFS distance dominantly use hip flexion to absorb the squat load, similar to reports on the favored usage of the hip extensor muscle in the effective squat [24] and shock absorbance by hip flexion in jump-landing [25, 26]. Injury of the anterior cruciate ligament in women soccer players has recently been reported to occur more frequently in the pivotal (left)

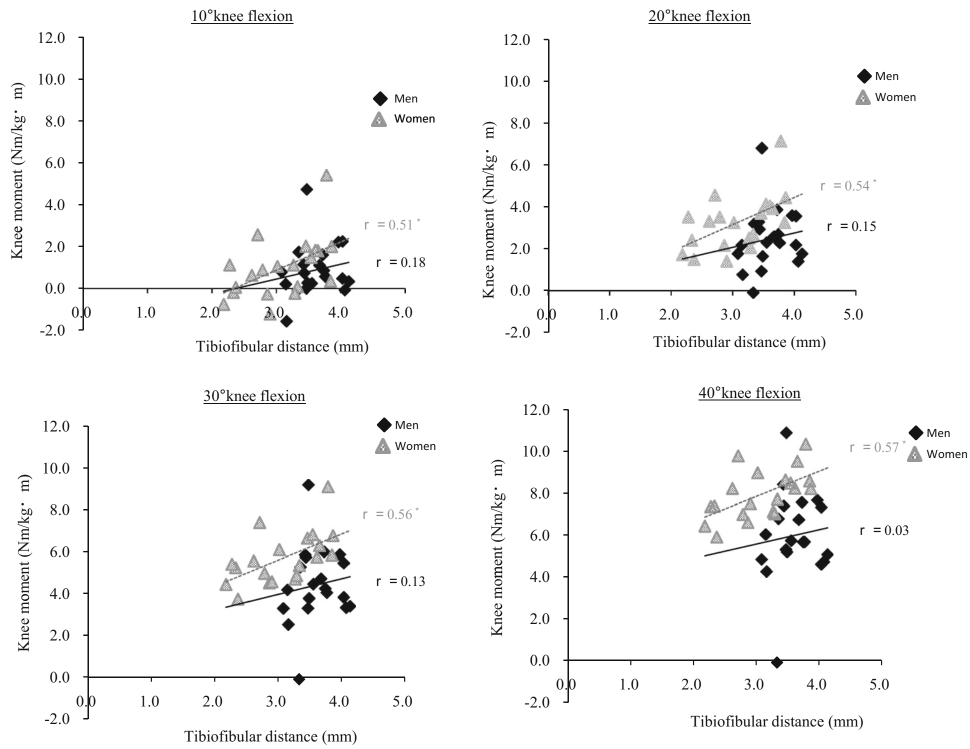

Fig. 2 Relation between TFS distance and knee moment at knee flexion angles of 10°, 20°, 30°, and 40°. *Abscissa* and *ordinate* TFS distance (mm) and knee moment (Nm/kg m), respectively. Linear regression lines for the groups of men (*solid line*) and women (*dotted line*) are shown

leg than in male soccer players [27]. The authors discussed the causation of this injury as being due to decreased lateral hip control in the context of decreased peak flexion angles upon jump-landing [27]. Our results show decreased hip flexion with a wider TFS distance, further providing support for a gender-related cause of the greater incidence of ACL injury among female soccer players.

Interestingly, in our female subjects with a relatively longer TFS distance, the hip flexion angle was smaller than that of their female counterparts with a shorter TFS distance, but it was equivalent to that of men, and the ankle dorsiflexion angle of the former group was relatively large, reaching a similar angle to that of the male subjects at deep squat conditions of 30°–40° knee flexion. Thus, elongation of TFS distance might alter the lower extremity dynamics in women, but not in men. Moreover, the estimated knee moment was positively correlated to the TFS distance in women, but not in men. These results suggest that women having a longer TFS distance perform squats with a relatively lower effective strategy to absorb the load, even with increased knee flexion moment, thereby providing more load to the ankle joint in parallel with a lower load to the hip joint. In other words, women having a longer TFS distance may have an increased risk to suffering damage to ankle and knee joints due to increased ankle loading, as it has often been reported that ankle instability reduces dynamic stability in the lower extremities [28–31]. Our results suggest the presence of some mechanism in women related to TFS distance which predisposes to a higher incidence of lower extremity injuries and which plays a the crucial role in the control of ankle function.

The reason for the gender difference described above is currently not well understood. We found that the TFS distance was somehow significantly correlated to body mass in men, but not in women. Men generally possess stronger muscles or a higher bone density than women. Therefore, TFS distance may not be a crucial factor in restricting the movements of the lower extremities in men. On the other hand, in our study TFS distance was not significantly related to the body mass in our female subjects, suggesting that TFS distance in women is affected by some intrinsic factor(s) inherent in women—but not structural factors of body mass or height. These factors are likely hormonal conditions affecting the muscle and bone metabolism, but further research is needed to clarify this issue.

Conclusion

In summary, we have investigated the gender difference in the relation of distance of TFS to joint dynamics of lower extremities during the squat movement. We found that in women with a relatively longer TFS distance, the hip flex angle decreased, the dorsal flexion angle increased, and the knee extension moment increased during squatting. This finding suggests that women with a longer TFS distance primarily use the knee and ankle during squat exercises and that this posture causes a movement pattern with increased knee extension moment, possibly leading to injury such as knee ligament lesion. It is possible that the evaluation of TFS distance can be used as an effective means to prevent sports injury in women.

Conflict of interest No conflicts of interest.

References

1. Garrick JG, Requa RK (1988) The epidemiology of foot and ankle injuries in sports. Clin Sports Med 7:29–36
2. Huang PY, Chen WL, Lin CF, Lee HJ (2014) Lower extremity biomechanics in athletes with ankle instability after a 6-week integrated training program. J Athl Train 49:163–172
3. Freeman MA (1965) Instability of the foot after injuries to the lateral ligament of the ankle. J Bone Jt Surg Br 47:669–677
4. Ross SE, Guskiewicz KM (2004) Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. Clin J Sport Med 14:332–338
5. Wikstrom EA, Tillman MD, Chmielewski TL, Cauraugh JH, Borsa PA (2007) Dynamic postural stability deficits in subjects with self-reported ankle instability. Med Sci Sports Exerc 39:397–402
6. Bartonícek J (2003) Anatomy of the tibiofibular syndesmosis and its clinical relevance. Surg Radiol Anat 25:379–386
7. Beumer A, Valstar ER, Garling EH, Niesing R, Ginai AZ, Ranstam J, Swierstra BA (2006) Effects of ligament sectioning on the kinematics of the distal tibiofibular syndesmosis: a radiostereometric study of 10 cadaveric specimens based on presumed trauma mechanisms with suggestions for treatment. Acta Orthop 77:531–540
8. Del Buono A, Florio A, Boccanera MS, Maffulli N (2013) Syndesmosis injuries of the ankle. Curr Rev Musculoskelet Med 6:313–319
9. Ebraheim NA, Taser F, Shafiq Q, Yeasting RA (2006) Anatomical evaluation and clinical importance of the tibiofibular syndesmosis ligaments. Surg Radiol Anat 28:142–149
10. Hunt KJ (2013) Syndesmosis injuries. Curr Rev Musculoskelet Med 6:304–312
11. Magan A, Golano P, Maffulli N, Khanduja V (2014) Evaluation and management of injuries of the tibiofibular syndesmosis. Br Med Bull 111:101–115
12. den Daas A, van Zuuren WJ, Pelet S, van Noort A, van den Bekerom MP (2012) Flexible stabilization of the distal tibiofibular syndesmosis: clinical and biomechanical considerations: a review of the literature. Strateg Trauma Limb Reconstr 7:123–129
13. Ogilvie-Harris DJ, Reed SC (1994) Disruption of the ankle syndesmosis: diagnosis and treatment by arthroscopic surgery. Arthroscopy 10:561–568
14. Ogilvie-Harris DJ, Reed SC, Hedman TP (1994) Disruption of the ankle syndesmosis: biomechanical study of the ligamentous restraints. Arthroscopy 10:558–560
15. Snedden MH, Shea JP (2001) Diastasis with low distal fibula fractures: an anatomic rationale. Clin Orthop Relat Res 382:197–205
16. Gerber JP, Williams GN, Scoville CR, Arciero RA, Taylor DC (1988) Persistent disability associated with ankle sprains: a prospective examination of an athletic population. Foot Ankle Int 19:653–660
17. Wright RW, Barile RJ, Surprenant DA, Matava MJ (2004) Ankle syndesmosis sprains in national hockey league players. Am J Sports Med 32:1941–1945
18. Arendt EA, Agel J, Dick RJ (1999) Anterior cruciate ligament injury patterns among collegiate men and women. Athl Train 34:86–92
19. Hosea TM, Carey CC, Harrer MF (2000) The gender issue: epidemiology of ankle injuries in athletes who participate in basketball. Clin Orthop Relat Res 372:45–49
20. Beighton P, Solomon L, Soskolne CL (1973) Articular mobility in an African population. Ann Rheum 32:413–418
21. Negrete RJ, Schick EA, Cooper JP (2007) Lower-limb dominance as a possible etiologic factor in noncontact anterior cruciate ligament tears. J Strength Cond Res 21:270–273
22. Ruedl G, Webhofer M, Helle K, Strobl M, Schranz A, Fink C, Gatterer H, Burtscher M (2012) Leg dominance is a risk factor for noncontact anterior cruciate ligament injuries in female recreational skiers. Am J Sports Med 40:1269–1273
23. Harris J, Fallat L (2004) Effects of isolated Weber B fibular fractures on the tibiotalar contact area. J Foot Ankle Surg 43:3–9
24. Lynn SK, Noffal GJ (2012) Lower extremity biomechanics during a regular and counterbalanced squat. J Strength Cond Res 26:2417–2425
25. Brown C, Bowser B, Simpson KJ (2012) Movement variability during single leg jump landings in individuals with and without chronic ankle instability. Clin Biomech (Bristol, Avon) 27:52–63
26. Myer GD, Ford KR, McLean SG, Hewett TE (2006) The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. Am J Sports Med 34:445–455
27. Brophy R, Silvers HJ, Gonzales T, Mandelbaum BR (2010) Gender influences: the role of leg dominance in ACL injury among soccer players. Br J Sports Med 44:694–697
28. Gribble PA, Hertel J, Denegar CR, Buckley WE (2004) The effects of fatigue and chronic ankle instability on dynamic postural control. J Athl Train 39:321–329
29. Gribble PA, Hertel J, Denegar CR (2007) Chronic ankle instability and fatigue create proximal joint alterations during performance of the Star Excursion Balance Test. Int J Sports Med 28:236–242
30. Gribble PA, Robinson RH (2009) Alterations in knee kinematics and dynamic stability associated with chronic ankle instability. J Athl Train 44:350–355
31. Shimokochi Y, Shultz SJ (2008) Mechanisms of noncontact anterior cruciate ligament injury. J Athl Train 43:396–408