Lower Extremity Overuse Conditions Affecting Figure Skaters During Daily Training

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Background: Most ice figure skaters train and compete with ongoing issues in the lower extremities, which are often overlooked by the skaters and considered injuries only when they prevent the athletes from skating. Although not severe, these conditions impair the quality of daily training and compromise the skaters' state of mind and performances.

Purpose: (1) To determine the point prevalence of the ongoing lower extremity overuse conditions in a population of ice figure skaters of all ages and levels and (2) to identify the risk factors contributing to the development of the most common ongoing conditions.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A total of 95 skaters of all ages and skating levels were evaluated in a single examination in the middle of the competitive season. Data collection consisted of a questionnaire, clinical examination, and measurement of the skaters' characteristics and the equipment used.

Results: Retrocalcaneal bursitis was the most common problem, affecting at least 1 foot in 34% of the skaters evaluated, followed by posterior heel skin calluses and superficial calcaneal bursitis, which affected 29% and 28% of skaters, respectively. The prevalence of the majority of these conditions was 10% to 32% higher in elite skaters than in nonelite skaters. Higher boot–foot length difference was associated with greater risk of superficial calcaneal bursitis in the landing foot of elite skaters, while higher body weight and greater in-skate ankle flexibility were associated with the development of retrocalcaneal bursitis in nonelite skaters. Only 30 skaters (32%) wore the appropriate boot size, while 57 skaters (51%) could not dorsiflex their ankles properly while wearing skates.

Conclusion: The heel represents a major area of concern for the high prevalence of calcaneal bursitis and calluses in proximity of the Achilles tendon, suggesting that improvements on the boot heel cup design should take priority. The association of bursitis with higher in-skate ankle flexibility suggests that these conditions may be the results of a process developing when the ankle is bending within the boot. Also, since wearing oversized boots is a major risk factor for the development of subcutaneous bursitis and skin abrasions, boot retailers should be better educated to sell the appropriate boot size to the skaters.

Keywords: figure skating; overuse injuries; foot deformities; skating boot; boot fit; prevalence of injury

Most ice figure skaters train and compete with ongoing issues in their lower extremities, such as tendinopathies, bursitis, lace bite, and hammer toes, which are often overlooked by the skaters and their coaches because they generally do not prevent the athletes from skating. These conditions generally develop over time, being the result of a process of overuse rather than a specific acute traumatic event. Although not severe, these conditions impair the quality of daily training and compromise the skaters' states of mind and performances. In addition, if not addressed, these conditions may worsen and force the athletes to stop training and competing.

The ice skate is thought to be a major contributor to the development of these ongoing conditions because of excessive boot stiffness and poor boot fit.[3-5,13,14,17-19] The skating boot is fabricated with varying degrees of stiffness to maximize the protection of the ankle joint from excessive motion in the frontal plane. However, with the current design, the boot also restricts the ankle motion in the sagittal plane, thus limiting its role in absorbing jump landing

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forces.[5] As a consequence, the shock wave generated at the landing impact then travels upward to the knee, hip, and back and can lead to excessive strain and load on these joints, which may lead to the development of overuse injuries over time.[3,5,8] A poor boot fit or a faulty alignment of the skater's foot in the boot generates frictional forces and excessive pressure in some areas of the foot that may lead to the development of foot and ankle conditions and deformities as physiological responses to stress. To reduce the incidence of jump- and fit-related overuse injuries, several authors suggested the need for improvement in skating boot design.[5,15,18]

An improved design of the skating boot requires a complete analysis of the clinical issues developed by figure skaters with the current boot design. This includes determining the spectrum and prevalence of these conditions to guide the new design, as well as the factors contributing to the development of these conditions, as a step toward injury prevention.[10]

Dubravcic-Simunjak et al[8] investigated the frequency of injuries in 469 elite junior-level skaters over a 4-year period. They found that 43% of the female skaters and 46% of the male skaters reported overuse syndromes, with stress fractures, jumper's knee, and shin splints being the most common conditions among single and pair skaters. However, injuries were only assessed retrospectively (using questionnaires), and it was unclear if skaters reported only those injuries forcing them to stop training or all conditions. More recently, 3 other studies investigated the incidence of injury in adult figure skaters[2,9] and synchronized figure skaters[7] or in synchronized figure skaters only.[7] Again, the injuries were only assessed retrospectively with questionnaires. An interesting review on the skin conditions in figure skaters, ice hockey players, and speed skaters has been recently published by Tlougan et al,[19] in which 11 types of mechanical dermatoses such as skaters' nodules, pump bumps, piezogenic pedal papules, and lace bite have been described. However, this study does not report any incidence or prevalence value for the overuse-related skin conditions in skaters. To our knowledge, no study has yet tried to determine the risk factors for the development of lower extremity overuse conditions in figure skaters.

Hence, the aims of this study were (1) to determine the point prevalence of the ongoing lower extremity conditions in a population of figure skaters of all ages and levels and (2) to identify the risk factors contributing to the development of the most common ongoing conditions.

METHODS

A total of 95 skaters training in 5 different Italian skating clubs were evaluated in a single examination during the middle of the competitive season 2013-2014 (November-December 2013). Inclusion criteria included having at least 1 year of skating experience in a skating club prior to the date of the evaluation and being active (ie, in on-ice training) at the time of evaluation. The subjects (20 male skaters, 75 female skaters), between the ages of 6 and 33 years (mean, 14.2 ± 5.6 years), represented several skating disciplines and skill levels (Table 1). This study was approved by the local ethics committee. All participants, or their parents in cases of underage skaters, signed informed consent forms.

TABLE 1
Description of the Study Population[a]

	No. of Skaters
Discipline type	Singles, 85; pairs, 10
Competitive level	No competitions, 19; local competitions, 40; national competitions, 19; international competitions, 17
Skating level	Up to single axel, 35; at least 1 single axel and 1 double jump, 27; at least all double jumps (elite skaters), 17; at least 1 double axel and 1 triple jump (elite skaters), 16
Boot brand	Edea, 69; Risport, 20; Graf, 2; other, 4
Skating club[b]	Skating club 1, 21; skating club 2, 27; skating club 3, 17; skating club 4, 20; skating club 5, 10

[a]Because only 2 dance skaters were examined in this study, their data were later excluded from the final results because dance skaters are nonjumping skaters and hence may be subjected to different types of lower extremity conditions.

[b]The skating club levels indicate the 5 different skating clubs, located in different regions of Italy, of the skaters evaluated.

Data Collection

Evaluations were performed at the skating clubs' facilities and lasted on average 35 minutes for each skater. Data collection consisted of a questionnaire, clinical examination, and measurement of the skaters' characteristics and equipment used.

The questionnaire was distributed to all skaters 1 week before the evaluation and consisted of 35 questions investigating the equipment used, training habits, skating skills, injury history, and location of any pain subjects may be experiencing at that time. The questionnaire was returned by the skaters at the time of the evaluation and checked for completion.

Next, a comprehensive physical examination was performed by the sport medicine doctor participating in this study (L.V.). The skaters' feet and ankles were screened for every deformity and skin condition that could be linked to the use of skates (eg, skin calluses, hammer toes, heel spurs, and skin abrasions and irritations), and the symptoms reported by the skater for the lower extremities were investigated. In many cases, an instrumental examination was also performed to understand the exact cause of the symptoms using ultrasonography (18-MHz linear array ultrasound transducer probe; MyLabOne; Esaote). The diagnosis of an overuse condition was made on the basis of the criteria reported in Table 2. Since the terminology of Achilles-related conditions is variable in the literature, the conditions found in the present study were named based on the study by Van Dijk et al.[21]

Several measurements were collected for each skater. The length of both feet (heel to toe) was determined using

TABLE 2
Diagnosis of Lower Extremity Overuse Conditions[a]

Condition	Clinical Findings	Ultrasound Findings
Retrocalcaneal bursitis	Painful soft tissue swelling, medial and lateral to the Achilles tendon at the level of the posterosuperior calcaneus	Anechoic area in the subtendinous area just above the calcaneus
Superficial calcaneal bursitis	Visible, painful, solid swelling area with discoloration of skin; most often located at the posterolateral calcaneus; in chronic bursitis, pain was only felt after the bursa was exposed to friction	Hypoechoic or anechoic area between the skin and the Achilles tendon; in case of chronic bursitis, a hyperechoic area can be seen between the skin and the Achilles tendon
Skin callus	Incompressible swollen area with ipercheratosis at the level of the Achilles insertion or its middle third with no associated redness unless just exposed to friction (shoe)	Hyperechoic area in the superficial subskin area with no deeper anechoic area
Skin abrasion	Grazed area	NA
Tendinopathies	Pain, swelling, and exercise-induced pain	Hypoechoic area in the tendon; sometimes thickened tendon for chronic conditions
Achilles paratendinopathy	Pain in the area of the Achilles and swelling, tenderness, and crepitus in the middle third of the Achilles	Hypoechoic layer is seen abutting posterior surface of the distal Achilles tendon
Osgood-Schlatter disease	Tenderness and swelling at insertion of patellar tendon at tibial tubercle in adolescents	Irregularity at the ossification nucleus of the tibial tubercle
Sever disease	Tenderness to palpation and in normal activity (eg, walking)	Irregularity at the ossification nucleus of the posterior calcaneus
Skin irritation on navicular bone medial prominence	Redness of the skin on the medial navicular and tenderness to palpation on the evident navicular bone prominence, generally due to overpronated flat foot	NA
Patellofemoral pain syndrome	Anterior knee pain “behind” or around patella. Also, possible findings of patellar maltracking	NA
Anterior talofibular ligament conditions	Tenderness to palpation on the lateral compartment of the ankle caused by tear or strain of the anterior talofibular ligament caused by a previous ankle sprain	Hypoechoic area on the ligament in case of strain; anechoic area in case of tear of the anterior talofibular ligament

[a]NA, not applicable.

a 3-dimensional (3D) foot laser scanner (ParoScan 3DV; Paromed). The foot scanner computed foot length with a 0.7-mm repeatability error. The maximum ankle dorsiflexion was assessed for both feet with the skaters being barefoot and wearing skates using a weightbearing lunge test.[1,12] When performing the lunge test in skates, blade guards were used to ensure a flat support. The heights of 3 off-ice countermovement jumps were determined using an optical system (Optojump; Microgate). The body weights of the skaters were determined using a commercial scale. The medial longitudinal arch type (ie, flat, normal, or cavus feet) was determined by performing a static plantar scan during full weightbearing using a footscan pressure plate (0.58 × 0.42 m, 64 × 64 resistive sensors, 500 Hz; RsScan International). The arch index method[6] was implemented in Matlab (Mathworks) to assess arch type. A qualitative check of the skaters' lacing techniques and of the general condition of the skating boot was also performed.

Data Analysis

The point prevalence of a given lower extremity condition was calculated as the percentage ratio of the number of skaters having the specific condition in 1 or both feet (confirmed by the physician after physical examination) to the total number of skaters evaluated. Skaters who were aged 9 years or younger were rarely diagnosed with any of the conditions listed in Table 2. Among them (skaters 6-9 years of age; n = 19), the only diagnosed conditions were posterior heel skin calluses (PHSCs) found in 3 skaters and retrocalcaneal bursitis (RCB) in 1 skater. As a result, the prevalence was computed only on skaters older than 9 years (range, 10-33 years; n = 76 skaters) to better represent the prevalence of injury in this group of skaters, who are at higher risk of injuries. Also, the prevalence was calculated for the subgroup of the elite skaters (defined in Table 1 as skaters able to perform at least all double jumps, at least a double axel, and 1 triple jump). We did so to determine the injury rate in this particular class of skaters considered at the highest risk of injuries. There were 33 elite skaters identified (18 male skaters, 15 female skaters), with an age range of 12 to 29 years (mean, 17.7 ± 4.2 years), training a mean (±SD) of 13.5 ± 4.1 hours on-ice per week. The injury prevalence was also calculated in nonelite skaters to directly compare their prevalence with the one computed for elite skaters.

The risk-factor analysis was performed by identifying 5 intrinsic athlete-related factors and 3 extrinsic environmental factors. The intrinsic factors were age, jump height, foot arch index, ankle flexibility, and body weight. Extrinsic factors were on-ice time, boot–foot length difference, and bendability score. The definition of each factor is reported in Table 3. Because skaters aged 9 years or younger were rarely diagnosed with any conditions, the risk factor analysis was performed only on older skaters. Since the

TABLE 3
Injury Risk Factors[a]

Age: Age in years of the skater at the time of the evaluation
Jump height: Computed (in cm) as the average of the 3 counter movement jumps
Foot arch index: Computed using the arch index method.[6] If the arch index was ≤0.21, the foot was considered cavus; if it was between 0.21 and 0.26, the foot was considered normal; if it was >0.26, the foot was considered flat
Ankle flexibility: Computed (in cm) with a lunge test as a knee-over-toe measurement performed barefoot
Body weight: Weight (in kg) of the skater at the time of the evaluation
On-ice time: Number of hours spent training on ice every week
Boot–foot length difference: Computed (in mm) as the difference between the length of the boot (stated by the manufacturer) and the length of the foot calculated using the foot laser scanner
Bendability score: Computed (in cm) as the difference between the knee-over-toe measurement performed barefoot and the knee-over-toe measurement performed in skates using the lunge test

[a]All risk factors were analyzed as continuous variables.

complete data sets for performing risk factor analysis were collected in 56 of 76 total skaters older than 9 years, and since only 10 skaters of 56 were wearing boot brands different from Edea, the risk factor analysis was performed on the 46 skaters wearing Edea boots to not confound the results of the analysis with other boot brands. Two separate analyses were computed for elite skaters (n = 21) and nonelite skaters (n = 25).

Generalized linear models were used to determine whether the 8 intrinsic and extrinsic factors were associated with increased risk for the most common conditions. Because the effects of these factors on the occurrence of the overuse conditions may differ between landing and contralateral foot, logistic regression models were computed for each foot separately. We then pursued a model-building approach, with each of the conditions as the dependent variable. Each of the 8 independent variables was separately added to the model, and the resulting increase in goodness of fit compared with the reference model was calculated using a likelihood ratio test.[22] Each independent variable whose likelihood ratio test showed a trend toward significance was included in the final model. For each retained independent variable, odds ratios (ORs) and 95% CIs were computed. For each injury model, factors that exhibited insufficient frequency across any of the different levels were not included in the analysis. All continuous independent variables were centered in all analyses. Statistical analyses were performed using R version 2.13.0 (R Development Core Team). Statistical significance was defined as $P \leq .05$.

The percentages of skaters using orthotics, gel pads, custom boots, or "punching out' their boots were also calculated to quantify the rate of athletes who felt uncomfortable with their skating boots. The lacing techniques were also qualitatively evaluated by considering whether the skaters were loosening boot laces down and pulling the boot tongue forward before fitting, the skaters tried to lock the heel back on the heel counter by inclining the foot with the toes upward for all the duration of lacing, or the skaters tightened the laces maximally near the instep and in a looser way in the upper part of the boots proximal to the ankle joint.

RESULTS

Prevalence of Lower Extremity Overuse Conditions

The most common ongoing conditions found in the 76 skaters evaluated in this study affected the foot and ankle, particularly the posterior aspect of the heel. RCB was the most common problem, affecting at least 1 foot of 26 skaters (34%), followed by PHSC and superficial calcaneal bursitis (SCB) (Table 4). All of these conditions were mostly bilateral, even if the severity of the problem was generally higher in the landing leg. Skaters had a mean (±SD) of 3.4 ± 3.3 ongoing conditions at the same time, which ranged from simple skin conditions (eg, calluses and abrasions) to musculoskeletal conditions (eg, tendinopathies, ligaments, and bone disorders). By excluding minor skin conditions (ie, anterior and lateral ankle skin abrasions and toe corns), the mean number of ongoing conditions was 2.6 ± 2.5 per skater.

The diagnosis of RCB was not associated with the presence of Haglund deformity, in contrast with several studies[13-15,20] relating the presence of RCB with an abnormal prominence of the posterior tuberosity (Figure 1, A and B). Superficial calcaneal bursitis was the most clearly visible problem among the skaters, which appears as a posterolateral heel prominence that generally creates pain when exposed to friction with the footwear (Figure 1, C and D). Ninety percent of athletes with SCB had a chronic condition, since fibrous bands within the bursal cavity were apparent (Figure 1, E and F). Skin calluses were mostly present at the posterior heel (PHSC), but also at the level of the Achilles middle third, where bursitis was also found in some skaters (Figure 1, G through K). Hard toe corns (TC) were generally present on the dorsolateral aspect of the fifth toe and on the dorsum of the proximal and sometimes distal interphalangeal joint of the lesser toes (Figure 1H), while lateral ankle skin abrasions (LASA) were found at the level of the skating boot collar (Figure 1I). The skin irritation found on the medial aspect of the navicular bone was caused by the friction generated from the interaction of the boot with a prominent medial side of the navicular bone (Figure 1J). However, the presence of an accessory tarsal navicular bone, reported as the cause of this condition in many studies, could not be confirmed with ultrasound.[13,14,20] In some elite skaters, piezogenic pedal papules were noted when looking at the pictures of the skaters' feet after the evaluation. These papules, which result from herniation of fat through the dermis, were not diagnosed during the physical examination because the skaters did not report any associated pain with this condition, and they could only be detected while weightbearing (Figure 1L).

In the group of elite skaters (n = 33), the prevalence of calcaneal bursitis was extremely high, with 26 elite skaters

TABLE 4
Point Prevalence of Lower Extremity Overuse Conditions in Skaters Older Than 9 Years (n = 76)[a]

	Prevalence, n (%)	Skaters With Bilateral Condition, n	Skaters With Unilateral Condition, n	
			Landing Foot	Contralateral Foot
RCB	26 (34)	13	6	7
PHSC	22 (29)	17	4	1
SCB	21 (28)	15	6	0
TC	19 (25)	16	2	1
LASA	16 (21)	13	3	0
Achilles middle-third skin callus/bursitis	12 (16)	6	5	1
Skin irritation on navicular bone medial prominence	10 (13)	9	1	0
Anterior ankle skin abrasion	9 (12)	6	3	0
Other[b]	<9 (<10)	—	—	—

[a]Conditions found in <4% of the population were not reported. LASA, lateral ankle skin abrasion; PHSC, posterior heel skin callus; RCB, retrocalcaneal bursitis; SCB, superficial calcaneal bursitis; TC, toe corns.
[b]Other conditions included Achilles paretendinopathy (7%), patellar tendon tendinopathies (7%), patellofemoral pain syndrome (7%), anterior talofibular ligament conditions (5%), Osgood-Schlatter disease (5%), and Sever disease (5%).

(79%) diagnosed with at least 1 RCB and/or SCB in 1 foot. The prevalence of the 4 most common lower extremity conditions in elite skaters was found to be 20% to 32% higher than the prevalence found for nonelite skaters older than 9 years (Table 5). In nonelite skaters, the most common problem was PHSC followed by RCB and TC, while the prevalence of SCB was substantially lower than that in elite skaters.

Risk Factor Analysis

Results from the stepwise generalized regression model analyses are summarized in Table 6 for elite skaters and in Table 7 for nonelite skaters. None of the analyzed factors was found to be associated with the risk of RCB in elite skaters. However, in nonelite skaters, an increased risk of developing RCB in the landing foot was found to be significantly associated with higher body weight (P = .01) and lower bendability score (ie, good in-skate flexibility; P = .05). In elite skaters, an increased risk of developing SCB in the landing foot was found to be significantly associated with a higher boot–foot length difference, a lower bendability score, and a lower jump height (P = .01, .01, and .02, respectively). While for the contralateral foot, an increased risk to develop SCB was found to be significantly associated with lower age, lower bendability score, and lower flexibility (P = .02, .02, and .003, respectively). Also, higher boot–foot length difference was found to be associated with a higher risk for LASA for the contralateral foot (P = .02) and the landing foot of elite skaters, although the effect was less significant in the landing foot (P = .07). LASA in the contralateral foot was also associated with the increase in the hours per week spent on ice (P = .02) and with lower jump height and bendability score (P = .004 and .008, respectively). Lower boot–foot length difference was the factor most significantly associated with the development of TC in elite skaters (P = .02). Finally, in nonelite skaters, PHSC was found to be significantly associated with higher age for both the landing foot and the contralateral foot (P = .03 and .02, respectively) and with lower jump height for the contralateral foot only (P = .04).

Among the extrinsic factors, we found that the boot size was appropriate only in a minority of the skaters evaluated. Hence, we decided to analyze this finding by defining the "boot–foot length mismatch" as the difference between the length of the boot (as stated by the manufacturer) and the length of the skater's longest foot (as the longest foot guides the choice of the boot size). As recommended by boot manufacturers, we considered the boot–foot length mismatch to be acceptable if within 5 mm for skaters who are 14 years or older and within 10 mm for skaters younger than 14 years. In particular, since the difference in boot length from one boot size to the next is 5 mm for Edea and Risport boots, a skater older than 14 years with boot–foot length mismatch of 20 mm was considered to have a boot 3 sizes bigger, while a skater of 14 years or younger with boot–foot length mismatch of 20 mm was considered to have a boot 2 sizes bigger. We found that the boot–foot length mismatch was appropriate in only 30 skaters (32%), whereas it was 1 to 5 sizes larger for the majority of skaters (Figure 2A). Since parents generally encourage young skaters to choose larger boots to accommodate rapid foot growth, we used linear regression analysis to test the hypothesis that younger skaters have higher boot–foot length mismatch (ie, excessively bigger boot sizes) than older skaters. Also, high-level skaters are generally better assisted in boot choice than low-level skaters because they can rely on experts in the field. Hence, an analysis of variance was performed to test the hypothesis that lower level skaters have higher boot–foot length mismatch than higher level skaters (competitive level groups defined in Table 1). We then conducted post hoc comparisons using Student pairwise t tests. Our results positively confirmed our 2 hypotheses, with the boot–foot length mismatch being significantly higher in younger skaters ($\beta = -0.53$; $P < .0001$; calculated on 93 skaters) and in lower level skaters (Figure 2B).

By analyzing the extrinsic factors, we also noted that the bendability score was typically higher (ie, less bendability

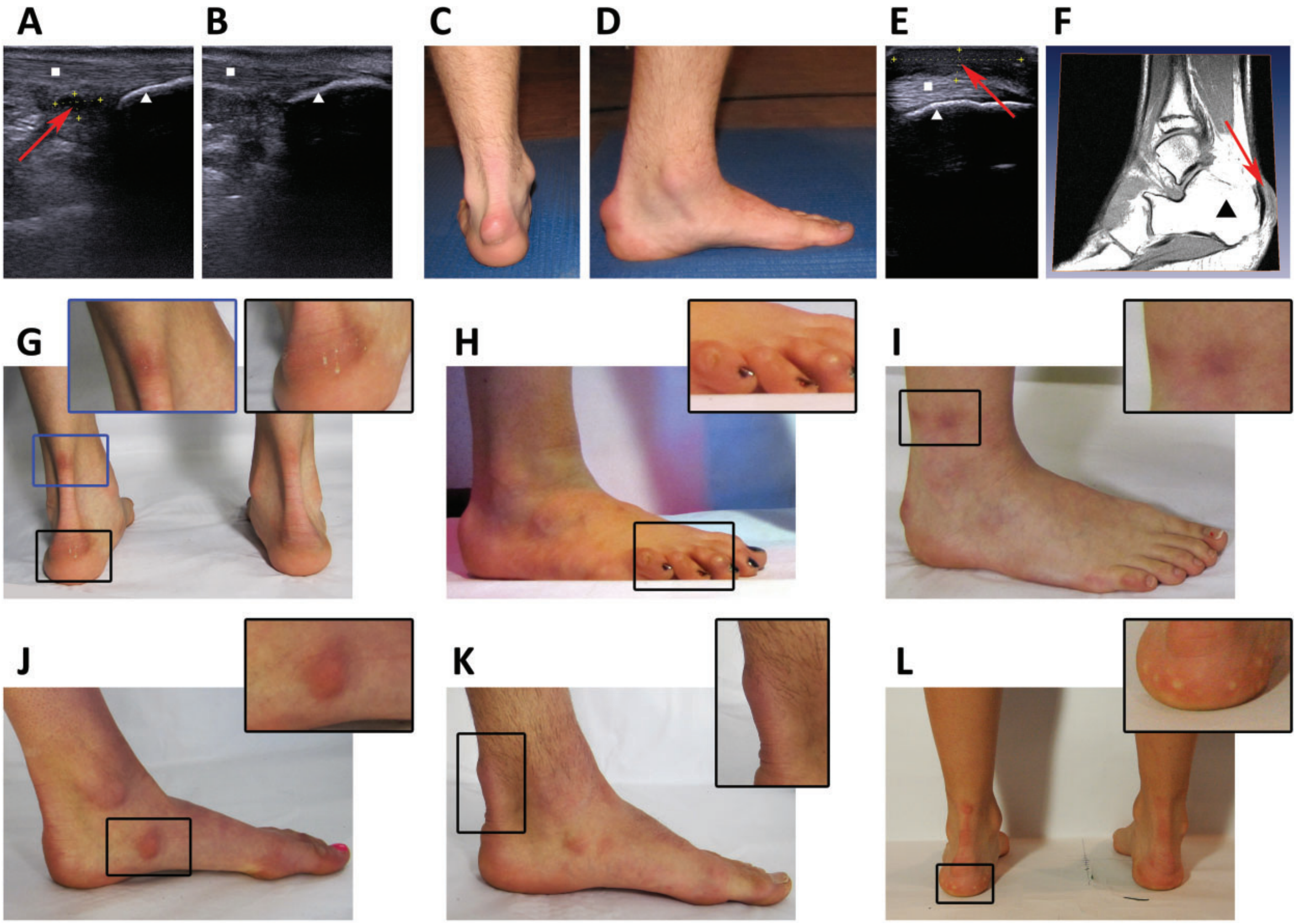

Figure 1. Foot ''hot spots'' in figure skaters. (A) Ultrasound image of the right foot of a skater with retrocalcaneal bursitis (RCB). A hypoechoic area (red arrow) can be seen between the Achilles tendon (square) and the calcaneus (triangle). The calcaneus profile looks normal, so Haglund deformity was not diagnosed. (B) Ultrasound image of the left foot of the same skater without RCB showing no hypoechogenic area between the Achilles tendon and the calcaneus. (C and D) Posterior and medial views of the left foot of a skater with a severe bilateral superficial calcaneal bursitis (SCB). Generally, skaters with SCB present a lump on the lateral side of the back of the heel in contrast with skaters with RCB, where the heel is swollen but does not have a defined lump. (E) Ultrasound image of the same foot reported in C and D showing an anechogenic or ipoechogenic area just above the Achilles tendon (square). (F) Sagittal magnetic resonance image (MRI) taken privately by the same skater shown in C, D, and E showing that the bursa is posterior to the Achilles tendon. (G) Skin calluses present in both the back of the heel and in the Achilles middle third. (H) Toe corns. (I) Lateral ankle skin abrasion at the level of the boot collar. (J) Skin irritation on the medial side of the navicular bone. (K) Achilles middle-third bursitis. (L) Piezogenic pedal papules in the left heel of a skater.

in skates than barefoot) in lighter skaters. Hence, we decided to further investigate this finding by defining the skater's bendability score as the average of the bendability scores computed for the 2 feet. The skater's bendability score is a measure of how much the skaters can bend their ankles in skates compared with barefoot, and is a direct consequence of the stiffness of the boot and the lacing technique. When performing the lunge test to assess the ankle dorsiflexion range of motion, one requirement for the test is that the heel should not be lifted when flexing the ankle. However, since the skating boot has high heels, the foot in skates lays with the rear foot higher than the forefoot, thus increasing the dorsiflexion range of motion. Hence, ideally, the range of dorsiflexion measured in skates should be higher than that measured barefoot. A negative value of the skater's bendability score indicates that the skater is able to bend more in skates than barefoot, which is considered ideal. A positive value of the skater's bendability score up to 2 cm was considered acceptable in this study, while score values higher than 2 cm were considered undesirable.[20] The results of our analysis showed that the skater's bendability score was ideal (ie, negative values of the bendability score indicate skaters were able to bend more in skates than barefoot) for 43 skaters (51%). While 28 skaters

TABLE 5
Point Prevalence of Lower Extremity Overuse Conditions in Elite Skaters and Nonelite Skaters Older Than 9 Years[a]

	Elite Skaters (n = 33)	Nonelite Skaters Older Than 9 y (n = 43)	Prevalence Increase in Elite Skaters, %
RCB	16 (49)	10 (23)	+26
SCB	15 (46)	6 (14)	+32
TC	12 (36)	7 (16)	+20
LASA	12 (36)	4 (9)	+27
PHSC	9 (27)	13 (30)	−3
Achilles middle-third skin callus/bursitis	9 (27)	3 (7)	+20
Anterior ankle skin abrasion	6 (18)	3 (7)	+11
Skin irritation on navicular bone medial prominence	5 (15)	5 (12)	+3
Achilles paratendinopathy	4 (12)	1 (2)	+10
Patellofemoral pain syndrome	4 (12)	1 (2)	+10
Anterior talofibular ligament conditions	4 (12)	0 (0)	+12
Other[b]	<4 (<12)	—	—

[a]Results are reported as n (%) unless otherwise indicated. The conditions are sorted from the most common to the least common in elite skaters. Conditions found in <4% of the population were not reported. LASA, lateral ankle skin abrasion; PHSC, posterior heel skin callus; RCB, retrocalcaneal bursitis; SCB, superficial calcaneal bursitis; TC, toe corns.

[b]Other conditions included patellar tendon tendinopathies (elite 9%; nonelite, 2%) and Osgood-Schlatter disease (elite, 6%; nonelite, 5%).

(33%) had a difference from 0 to 2 cm knee-over-toe from the barefoot test, 14 skaters (17%) had a more than 2-cm knee-over-toe difference from the barefoot test. Next, we performed a regression model relating the skater's bendability score to weight, controlling for age and jump height of the skaters (between 2 skaters with the same weight, the less powerful skater may be more penalized by a stiffer boot than a more powerful skater), to test the hypothesis that lighter skaters have poorer bendability score. Linear regression analysis showed a significant negative association of the skater's bendability score (ie, high values of the bendability score) with weight of the skaters ($P < .0001$, calculated on 77 skaters), indicating that lighter skaters had poorer bendability scores than heavier skaters.

DISCUSSION

The present study describes, for the first time, overuse conditions affecting the lower extremities of figure skaters of different ages, levels, and skating disciplines during daily training. The skaters and their equipment have been evaluated, and typical common "hot spots" on the skaters' feet have been identified (Figure 1). The risk factors for the development of the most prevalent conditions were also assessed among several extrinsic and intrinsic factors for elite and nonelite skaters.

Prevalence of Lower Extremity Conditions

Our results show that the most prevalent ongoing conditions in figure skaters affect the foot and ankle, as confirmed by the high percentages of skaters using protective gel pads (28%) and "punching out" their boots (21%) to relieve pain (see Appendix, Section A3). The heel represents a major area of concern for the high prevalence of calcaneal bursitis and calluses in proximity to the Achilles tendon. RCB and SCB represent the most serious foot and ankle issues for skaters because they cause pain and are very common, especially in elite skaters, where the prevalence of this condition was more than 45%. Toe corns and ankle abrasions are less serious because they cause only mild or no pain. However, they are symptoms of a wrong interaction of the foot and ankle with the skating boot, which may alter more important anatomic structures over time if not corrected (eg, lace bite/skate bite). These findings suggest that improvements on the boot heel cup and the boot collar designs should take priority to reduce these high prevalences.

Jump-related overuse conditions (eg, Achilles paratendinopathy, patellofemoral pain syndrome, Osgood-Schlatter disease, and Sever disease) are less prevalent than boot fit–related issues (eg, SCB, skin calluses, and abrasions). The most common jump-related overuse issues in elite skaters were Achilles paratendinopathy (12%), patellofemoral pain syndrome (12%), patellar tendinopathy (9%), and Osgood-Schlatter disease (6%). Dubravcic-Simunjak et al[8] reported similar prevalences in elite single and pair skaters for patellar tendinopathy (11%) and Osgood-Schlatter disease (9%), while they reported a lower percentage of Achilles tendinitis (3%) and no cases of patellofemoral pain syndrome. The landing leg was not more frequently affected by overuse conditions than the contralateral leg, even if the severity of the condition in the landing leg was generally worse. This finding, confirmed also by the study from Dubravcic-Simunjak et al,[8] supports the fact that overuse conditions occur not only because of the greater impact on the landing leg (which is always the same for the skater), but also because of the repetitive jump take-off (the landing leg is used for jump take-off for loop, flip, and lutz jumps, while the contralateral leg is used for jump take-off for axel, toe-loop, and salchow jumps) and other bilateral skating moves.

Our study was the first to compare the prevalence of overuse conditions at the lower extremities in elite and nonelite skaters. We found that PHSC and RCB are the most common ongoing conditions in nonelite skaters, while RCB and SCB are the most common conditions in elite-skaters. Nonelite skaters tend to develop calluses at the Achilles tendon insertion, while elite skaters develop SCB. Also, nonelite skaters rarely suffered jump-related conditions. Interestingly, skaters younger than 9 years of age rarely developed any of the described conditions. One

TABLE 6
Results of the Risk Factor Analysis for the Landing and Contralateral Foot in Elite Skaters (n = 21)[a]

		Risk Factor							
Injury	Foot	Age, y	Jump Height, cm	Foot Arch Index	Ankle Flexibility, cm	Body Weight, kg	On-Ice Time, h/wk	Boot–Foot Length Difference, mm	Bendability Score, cm
RCB	LF	—	—	—	—	—	—	—	0.795 (0.509-1.072); $P = .138$
	CLF	1.239 (0.975-1.671); $P = .08$	—	—	—	—	—	—	—
SCB	LF	—	0.759 (0.482-0.969); $P = .022^b$	0.154 (0.006-1.077); $P = .061$	0.714 (0.369-1.086); $P = .125$	—	0.704 (0.37-1.017); $P = .061$	1.372 (1.07-2.182); $P = .008^b$	0.498 (0.094-0.908); $P = .014^b$
	CLF	0.576 (0.208-0.939); $P = .02^b$	—	—	0.389 (0.101-0.798); $P = .003^b$	—	—	—	0.604 (0.3-0.93); $P = .019^b$
PHSC	LF	×	×	×	×	×	×	×	×
	CLF	×	×	×	×	×	×	×	×
LASA	LF	×	0.887 (0.718-1.027); $P = .116$	×	—	—	—	1.155 (0.992-1.428); $P = .065$	0.773 (0.479-1.07); $P = .122$
	CLF	×	0.411 (0.029-0.866); $P = .004^b$	×	—	—	3.252 (1.135-107.997); $P = .016^b$	2.03 (1.056-18.117); $P = .023^b$	0.353 (0.028-0.852); $P = .008^b$
TC	LF	—	—	—	—	×	1.378 (1.014-2.179); $P = .04$	0.798 (0.581-0.963); $P = .015$	—
	CLF	×	—	×	0.638; (0.315-1.006) $P = .054^b$	—	—	0.79 (0.566-0.964); $P = .016^b$	—

[a]Results are reported as odds ratio (95% CI). × = not included (occurrence of injury variable [yes/no] at 0 in ≥1 level of the factor); — = dropped in the stepwise generalized linear model (ie, measure whose likelihood ratio test was not significant). CLF, contralateral foot; LASA, lateral ankle skin abrasion; LF, landing foot; NA, no analysis (<5 individuals with or without the corresponding injury); PHSC, posterior heel skin callus; RCB, retrocalcaneal bursitis; SCB, superficial calcaneal bursitis; TC, toe corns.
[b]The association between the factor and the condition is statistically significant ($P \leq .05$).

TABLE 7
Results of the Risk Factor Analysis for the Landing Foot and the Contralateral Foot in Nonelite Skaters (n = 25)[a]

		Risk Factor							
Injury	Foot	Age, y	Jump Height, cm	Foot Arch Index	Ankle Flexibility, cm	Body Weight, kg	On-Ice Time, h/wk	Boot–Foot Length Difference, mm	Bendability Score, cm
RCB	LF	—	1.444 (0.888-3.383); $P = .155$	—	2.165 (0.8-19.088); $P = .153$	1.296 (1.056-2.116); $P = .007^b$	—	—	0.237 (0.014-1.023); $P = .054^b$
	CLF	×	×	×	×	×	×	×	×
PHSC	LF	1.654 (1.058-3.043); $P = .025^b$	—	—	—	—	—	—	—
	CLF	2.204 (1.122-6.521); $P = .016^b$	0.708 (0.44-0.992); $P = .044^b$	—	—	—	—	—	—

[a]Results are reported as odds ratio (95% CI). × = not included (occurrence of injury variable [yes/no] at 0 in ≥1 level of the factor); — = dropped in the stepwise generalized linear model (ie, measure whose likelihood ratio test was not significant). CLF, contralateral foot; LF, landing foot; PHSC, posterior heel skin callus; RCB, retrocalcaneal bursitis.
[b]The association between the factor and the condition is statistically significant ($P \leq .05$). As the occurrence of injury was very low in the 25 nonelite skaters, the analysis was computed only for RCB and PHSC.

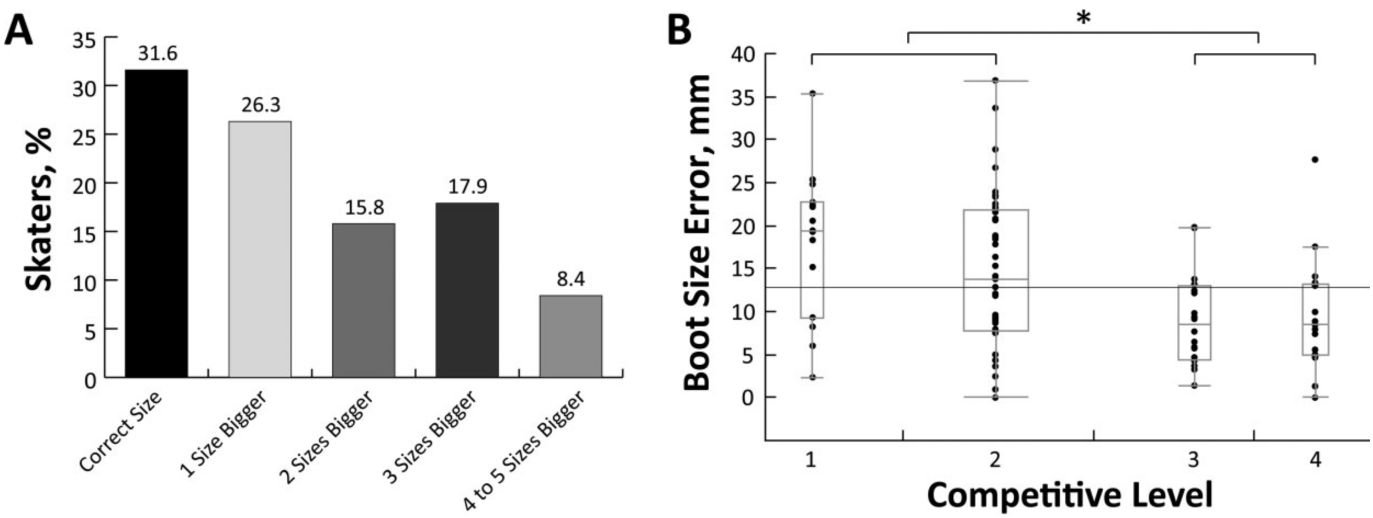

Figure 2. (A) Boot–foot length mismatch expressed as increment in boot size. A total of 68% of the skaters had a misfitted boot. (B) Boot size error and competitive level. Pairwise *t* test: 1-2, *P* > .08; 1-3, *P* = .001*; 1-4, *P* = .002*; 2-3, *P* = .011*; 2-4, *P* = .022*. *Statistically significant difference between elite and nonelite skaters (*P* ≤ .05).

possible explanation is that the skeletal structure of these young athletes is under development, hence it is very plastic and able to adapt to the excessive pressure and friction under a certain threshold.

Risk Factors for Lower Extremity Conditions

The risk-factor analysis showed that RCB is not affected by the jump height or on-ice time in elite and nonelite skaters, contrary to what may be expected for a jump-related overuse condition. The higher body weight represents a risk factor for the development of RCB in the landing foot of nonelite skaters, with an increased risk by 30% for each additional kilogram of weight. Interestingly, the more the nonelite skaters can bend the landing ankle in-skate, the higher the risk of developing an RCB, which suggests that repetitive deep dorsiflexion movements contribute to the development of RCB in the landing leg. Indeed, compression of the retrocalcaneal bursa occurs every time the ankle is dorsiflexed,[16] and repetitions are countless in the landing leg because of jump landings and take-offs. An increase in the bendability score is not associated with higher risk of RCB in the contralateral leg; this can be explained by the fact that while the landing ankle experiences high dorsiflexion for jump landing and jump take-off, the contralateral leg experiences this for jump take-off only, and, as a consequence, the effect of ankle dorsiflexion may not be as strong. None of the analyzed factors seem to be associated with the development of RCB in elite skaters, which suggests that future studies need to evaluate a higher number of elite skaters and to consider different factors from the one tested in this analysis.

The development of SCB has often reported to be associated with heel slippage, and here it was shown that the boot–foot length difference is the major risk factor for the landing foot of elite skaters, with 37% increased risk of SCB for every additional millimeter of boot–foot length difference. Surprisingly, we found that higher risk of SCB is associated with lower ankle flexibility in the contralateral foot and lower jump height in the landing foot, and one possible explanation for this finding is that the presence of SCB may limit the range of motion of the ankle, thus decreasing the jumping power.

The development of PHSC in nonelite skaters seems to be associated mostly with older age, while TC develop more frequently in skaters with a small boot–foot length difference, with 21% increased risk for every less millimeter of boot–foot length difference. LASAs develop more frequently in skaters with higher boot–foot length differences. One possible explanation for this behavior is that skaters who do not feel that the boot is tight enough around the ankle tend to lace the boot too tightly around the ankle area, which may cause the development of LASA.

According to our analysis, 68% of skaters wore oversized boots. Oversized boots reduce comfort, as each anatomic structure of the foot is not on the designed spot within the boot, causing premature failure of the product, and it is associated with a higher risk of developing SCB in the landing foot and LASA. The boot retailer generally decides boot size after measuring the length of the feet. These measurements are performed with various methods (eg, Brannock device, foot impression kit, drawing of plantar foot contour, rule of the 2 fingers gap on the back part of the boot) with potentially different accuracies, which have never been determined or compared. The Brannock measuring device is probably the most complete and accurate system for determining shoe size because it is calibrated and can measure foot length, arch length, and foot width.[11] However, the Brannock device is not the preferred method for the majority of retailers.

This study showed that 49% of skaters cannot bend their ankles enough while wearing skating boots and that the risk of a poor bendability score is higher in lighter skaters than in heavier skaters. Typically, boot retailers choose the appropriate boot stiffness for the skaters based only on the skaters' skating levels, which is defined by the type of jumps the athlete can land consistently (eg, single, double, or triple jumps). Hence, an 11-year-old girl weighing 35 kg and landing a triple jump is given the same boot stiffness of an 18-year-old boy weighing 85 kg and landing a triple jump. This study suggests that the stiffness of the boot should depend on the weight of the skater rather than on the skating/jump level only.

One limitation of this study was the inability to precisely diagnose those bone conditions that require additional imaging examinations, such as os tibialis, hallux valgus, and ongoing stress fractures. In addition to bone conditions, lower back pain was also not included in the analysis because magnetic resonance imaging was necessary to perform a complete diagnosis (lower back pain was a complaint of 18% of skaters older than 9 years and 21% of elite skaters). A second limitation of the study was that the lower extremity conditions were included regardless of whether they affected training or performance. A third limitation of this study deals with the fact that the spectrum of the conditions found in the athletes highly depends on the boot brand used by the skaters, because each manufacturer uses different foot last, heel height, and materials. Hence, the prevalence found in this study cannot be generalized to skaters wearing different boot brands.

CONCLUSION

Ongoing foot and ankle conditions are very common in skaters, and the heel represents a major area of concern for the high prevalence of calcaneal bursitis and calluses in proximity of the Achilles tendon, suggesting that improvements on the boot heel cup design should take priority. This study has shown that the type and prevalence of the skaters' conditions is different between elite and nonelite skaters. Indeed, the majority of the conditions found in skaters were 10% to 32% higher in elite skaters than in nonelite skaters, and nonelite skaters rarely develop impact-related overuse injuries and SCB. Our study suggested that jump take-off and other bilateral skating moves, in addition to landing impact, can importantly contribute to the development of these conditions. Some important risk factors have been found in this study to be associated with the most common conditions. Wearing oversized boots is a risk factor for the development of SCB and LASA, while increased body weight is the major risk factor for the development of RCB in nonelite skaters. Also, the association of RCB, SCB, and LASA with higher in-skate flexibility suggests that these conditions may be the results of a process developing when the ankle is bending within the boot. Finally, we have determined that boot retailers generally sell oversized and overstiff boots, which may alter the skaters' comfort and performance, increase the injury risk, and lead to premature boot failure. Hence, our study suggests that greater effort must be put on the education of boot retailers to measure the correct foot size and that a change in the criteria used to choose the proper boot stiffness for the athletes is necessary to not overpower lighter skaters. Other studies are needed to determine the point prevalence of lower extremity overuse conditions in skaters wearing other boot brands.

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APPENDIX

TABLE A1
Risk Factors in the Injured and Noninjured Foot Groups for Elite Skaters[a]

			Risk Factor							
Injury	Foot	n	Age, y	Jump Height, cm	Foot Arch Index	Ankle Flexibility, cm	Body Weight, kg	On-Ice Time, h/wk	Boot–Foot Length Difference, mm	Bendability Score, cm
RCB	LF									
	Injured	7	18.14 ± 5.73	39.01 ± 7.42	1.94 ± 0.64	11.21 ± 2.07	62.39 ± 8.86	12.21 ± 3.41	9.8 ± 6.02	–3.56 ± 4.99
	Noninjured	14	17.5 ± 3.18	36.48 ± 8.66	1.76 ± 0.86	9.42 ± 3.62	59.52 ± 11.22	14.29 ± 5.29	11 ± 7.74	–1.35 ± 1.8
	CLF									
	Injured	6	20.17 ± 5.81	36.38 ± 8.18	1.84 ± 1.05	10.04 ± 1.92	60.38 ± 11.4	14.17 ± 2.93	8.93 ± 5.86	–3.52 ± 5.5
	Noninjured	15	16.73 ± 2.81	37.7 ± 8.42	1.81 ± 0.7	10.01 ± 3.71	60.51 ± 10.34	13.37 ± 5.4	11.09 ± 7.03	–1.51 ± 1.81
SCB	LF									
	Injured	12	16.67 ± 2.64	34.77 ± 5.93	1.79 ± 0.78	9.48 ± 3.67	58.17 ± 11.25	12.75 ± 5.23	11.87 ± 7.49	–2.53 ± 4.00
	Noninjured	9	19.11 ± 5.28	40.73 ± 9.78	1.87 ± 0.82	10.74 ± 2.62	63.54 ± 8.7	14.72 ± 4.07	8.91 ± 6.53	–1.48 ± 2.02
	CLF									
	Injured	9	17 ± 2.92	34.32 ± 5.57	1.97 ± 0.62	8.56 ± 3.68	59.96 ± 12.41	13.39 ± 5.8	11.43 ± 7.66	–2.83 ± 4.13
	Noninjured	12	18.25 ± 4.81	39.58 ± 9.27	1.71 ± 0.9	11.12 ± 2.51	60.87 ± 9.1	13.75 ± 4.09	9.76 ± 6.03	–1.52 ± 2.5
PHSC	LF									
	Injured	4	20.25 ± 7.09	40.88 ± 8.53	1.6 ± 0.54	10.85 ± 3.69	63.88 ± 11.71	14.5 ± 3.11	5.91 ± 3.75	–2.71 ± 2.12
	Noninjured	17	17.12 ± 3.04	36.49 ± 8.12	1.87 ± 0.83	9.82 ± 3.23	59.68 ± 10.24	13.38 ± 5.13	11.7 ± 7.3	–1.94 ± 3.53
	CLF									
	Injured	4	21 ± 6.32	40.62 ± 8.38	1.34 ± 0.41	10.79 ± 3.61	63.85 ± 11.72	13.88 ± 4.33	5.72 ± 4.38	–2.34 ± 2.55
	Noninjured	17	16.94 ± 3.13	36.55 ± 8.18	1.93 ± 0.82	9.84 ± 3.25	59.68 ± 10.24	13.53 ± 4.98	11.59 ± 6.68	–2.02 ± 3.49
LASA	LF									
	Injured	8	17.75 ± 3.41	35.29 ± 6.29	1.67 ± 0.95	10.24 ± 2.91	59.6 ± 10.84	13.88 ± 6.54	13.07 ± 8.52	–2.78 ± 4.75
	Noninjured	13	17.69 ± 4.55	38.58 ± 9.14	1.91 ± 0.68	9.88z± 3.55	61.02 ± 10.46	13.42 ± 3.57	9.08 ± 5.89	–1.65 ± 2.05
	CLF									
	Injured	6	18.17 ± 3.92	34.17 ± 6.09	1.76 ± 0.84	9.36 ± 2.66	56.97 ± 9.91	15.83 ± 6.43	12.93 ± 8.54	–3.29 ± 5.42
	Noninjured	15	17.53 ± 4.24	38.59 ± 8.72	1.85 ± 0.79	10.28 ± 3.5	61.88 ± 10.53	12.7 ± 3.82	9.49 ± 5.78	–1.6 ± 1.98
TC	LF									
	Injured	6	20.17 ± 4.07	36.62 ± 9.57	1.96 ± 0.84	8.11 ± 3.98	57.03 ± 10.5	16.17 ± 2.79	6.39 ± 2.73	–2.64 ± 5.36
	Noninjured	15	16.73 ± 3.75	37.61 ± 7.89	1.76 ± 0.78	10.78 ± 2.68	61.85 ± 10.34	12.57 ± 5.06	12.29 ± 7.64	–1.86 ± 2.21
	CLF									
	Injured	7	20.14 ± 3.72	36.83 ± 8.76	2.03 ± 0.58	7.77 ± 3.74	60.14 ± 12.63	15.57 ± 2.99	5.61 ± 2.42	–2.48 ± 4.91
	Noninjured	14	16.5 ± 3.78	37.57 ± 8.19	1.72 ± 0.87	11.14 ± 2.38	60.64 ± 9.56	12.61 ± 5.25	12.91 ± 6.79	–1.89 ± 2.29

[a]Data are reported as mean ± SD. CLF, contralateral foot; LASA, lateral ankle skin abrasion; LF, landing foot; PHSC, posterior heel skin callus; RCB, retrocalcaneal bursitis; SCB, superficial calcaneal bursitis; TC, toe corns.

TABLE A2
Risk Factors in the Injured and Noninjured Leg Groups for Nonelite Skaters[a]

			Risk Factor							
Injury	Foot	n	Age, y	Jump Height, cm	Foot Arch Index	Ankle Flexibility, cm	Body Weight, kg	On-Ice Time, h/wk	Boot–Foot Length Difference, mm	Bendability Score, cm
RCB	LF									
	Injured	5	14.8 ± 2.49	28.52 ± 2.01	1.93 ± 0.54	10.7 ± 2.58	51.82 ± 8.83	7.5 ± 1.8	12.47 ± 5.91	–0.4 ± 1.63
	Noninjured	20	11.55 ± 1.61	25.47 ± 4.11	1.44 ± 0.93	9.95 ± 2.8	39.47 ± 7.57	6.78 ± 3.47	13.43 ± 9.5	0.62 ± 1.59
	CLF									
	Injured	4	15.25 ± 2.63	28.3 ± 2.25	1.53 ± 0.89	10.81 ± 2.96	54.3 ± 7.93	6.88 ± 1.31	14.93 ± 6.55	–0.19 ± 1.8
	Noninjured	21	11.62 ± 1.6	25.66 ± 4.1	1.51 ± 0.9	9.96 ± 2.73	39.59 ± 7.39	6.93 ± 3.45	12.55 ± 8.68	0.54 ± 1.6
PHSC	LF									
	Injured	9	13.44 ± 2.6	26.57 ± 3.67	1.58 ± 0.84	10.06 ± 2.36	46.36 ± 10.9	6.22 ± 1.94	15.12 ± 10.47	0.19 ± 1.85
	Noninjured	16	11.5 ± 1.63	25.81 ± 4.19	1.51 ± 0.93	10.12 ± 2.98	39.46 ± 7.23	7.31 ± 3.71	12.17 ± 7.88	0.55 ± 1.52
	CLF									
	Injured	7	13.29 ± 2.93	25.11 ± 2.59	1.82 ± 0.71	9.32 ± 2.15	46.33 ± 12.42	5.71 ± 1.82	14.91 ± 11.72	0.07 ± 2.01
	Noninjured	18	11.78 ± 1.77	26.46 ± 4.37	1.4 ± 0.93	10.4 ± 2.92	40.23 ± 7.26	7.39 ± 3.51	12.16 ± 6.83	0.56 ± 1.48

[a]Data are reported as mean ± SD. CLF, contralateral foot; PHSC, posterior heel skin callus; RCB, retrocalcaneal bursitis.

Section A3

Gel pads were used by 27 skaters (28%) to protect the heel area and the ankle at the level of the boot collar from high local pressure applied by the skating boot. Twenty skaters (21%) had their boots "punched out" to reduce the local pressure applied by the boot on specific areas of the foot and ankle or, more rarely, to lengthen the boot by punching out the tip. Only 12 skaters (13%) wore custom boots. Twenty-eight skaters (30%) used special orthotics while skating, with 16 skaters (17%) wearing custom orthotics and 12 (13%) skaters wearing over-the-counter orthotics. Generally, orthotics were used by skaters needing foot arch support or added cushioning and, more rarely, to fill the foot-boot gap because the boot size was too large. Finally, 11 skaters (12%) correctly loosened the laces and pulled the tongue forward before fitting the boot, 51 skaters (54%) correctly inclined the boot with the toes up for the duration of the lacing, and only 17 skaters (18%) reduced the tightness of the lacing going from the bottom to the uppermost eyelet to allow increased ankle flexibility.