

# Risk Factors for Lower Extremity Overuse Injuries in Female Youth Soccer Players

John W. O'Kane,<sup>\*†</sup> MD, Moni Neradilek,<sup>‡</sup> MS, Nayak Polissar,<sup>‡</sup> PhD, Lori Sabado,<sup>†</sup> PT, Allan Tencer,<sup>†</sup> PhD, and Melissa A. Schiff,<sup>§||</sup> MD, MPH

*Investigation performed at the University of Washington, Seattle, Washington, USA*

**Background:** Youth soccer injuries are common and of increasing concern, with sport specialization occurring at younger ages. Limited research is available regarding overuse injuries and risk factors in young female athletes.

**Purpose:** To identify the number and rate of overuse injuries in female soccer players (ages 12-15 years), describe the anatomic location and type of injury, and evaluate contributing risk factors.

**Study Design:** Case-control study; Level of evidence, 3.

**Methods:** A total of 351 female youth soccer players, ages 12 to 15 years, from Washington State were evaluated from 2008 to 2012. Players with lower extremity overuse injuries were identified through weekly emails and were interviewed by telephone to obtain data on injury type and body region. We evaluated the association between overuse injuries and preseason risk factors, including joint hypermobility, hip and knee muscle strength, and jump biomechanics, using Poisson regression to estimate relative risk (RR) and 95% CIs.

**Results:** The incidence rate for first-time lower extremity overuse injuries was 1.7 per 1000 athlete-exposure hours (AEH; 95% CI, 1.4-2.2), and that for repeat injuries was 3.4 per 1000 AEH (95% CI, 2.1-5.6). Knee injuries accounted for 47% of overuse injuries. Increased valgus was associated with a 3.2-fold increased risk (95% CI, 1.52-6.71) for knee injury. A 1-standard deviation (SD) increase in hamstring strength was associated with a 35% decreased risk (RR, 0.65; 95% CI, 0.46-0.91) for overuse knee injuries, and a 1-SD increase in quadriceps strength was associated with a 30% decreased risk (RR, 0.70; 95% CI, 0.50-0.98). A 1-SD increase in hip flexor strength was associated with a 28% decreased risk (RR, 0.72; 95% CI, 0.51-1.00) for overuse knee injuries, and a 1-SD increase in external rotation strength was associated with a 35% decreased risk (RR, 0.65; 95% CI, 0.46-0.91). Playing on more than 1 soccer team was associated with a 2.5-fold increased risk (95% CI, 1.08-5.35) for overuse knee injuries, and participating in other physical activities was associated with a 61% decreased risk (odds ratio, 0.39; 95% CI, 0.15-0.81).

**Conclusion:** In this study, lower extremity overuse injuries in female youth soccer players affected primarily the knee. Lower knee separation distance, decreased lower extremity strength, and playing on more than 1 soccer team increased injury risk.

**Keywords:** overuse injury; female athlete; youth sports; soccer; knee injury

\*Address correspondence to John W. O'Kane, MD, UWMC Stadium Sports Medicine Clinic, 3800 Montlake Blvd NE, Box 354060, Seattle, WA 98195, USA (email: jokane@uw.edu).

†Department of Family Medicine and Orthopedics and Sports Medicine, University of Washington, School of Medicine, Seattle, Washington, USA.

‡The Mountain-Whisper-Light Statistics, Seattle, Washington, USA.

§Harborview Injury Prevention and Research Center, Seattle, Washington, USA.

||Department of Epidemiology, University of Washington, School of Public Health, Seattle, Washington, USA.

One or more of the authors has declared the following potential conflict of interest or source of funding: This research was funded by the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health (grant RO1AR051059).

Ethical approval for this study was obtained from the University of Washington Human Subjects Review Committee (application No. 07-8511-A 01).

The Orthopaedic Journal of Sports Medicine, 5(10), 2325967117733963

DOI: 10.1177/2325967117733963

© The Author(s) 2017

In 2014, US Youth Soccer reported more than 3 million registered youth players, 48% of whom were girls.<sup>36</sup> While the benefits of youth sports are well documented,<sup>19</sup> youth soccer is a significant cause of pediatric injuries.<sup>1,14</sup> Studies of male professionals are numerous, while studies of females are less common, and there are relatively few studies of youth players.

Injuries are mechanistically divided into acute and overuse. Acute injuries involve a clearly identifiable trauma or incident, while overuse injuries occur secondary to repetitive microtrauma, without a single identifiable responsible event.<sup>6</sup> Most of the soccer literature focuses on acute injuries or evaluates both overuse and acute injuries together, resulting in a paucity of literature evaluating risk factors for overuse injuries. Further complicating overuse injury data collection and the interpretation of findings is a lack of consensus on the definition of overuse injury. Roos and Marshall<sup>31</sup> in a systematic review of the term *overuse injury* found that *overuse* could indicate a mechanism or a

definition, and a number of studies of overuse injuries do not state the injury criteria. The authors concluded that by definition, overuse injuries should have a mechanism of gradual onset with pathogenesis of repetitive microtrauma.

It is imperative in the study of youth soccer that overuse injuries are assessed, because they comprise a greater proportion of injuries in younger athletes,<sup>13</sup> and the immature skeleton is at increased risk of osteochondrosis, with the potential to affect future growth.<sup>26</sup> The opportunity and pressure for young athletes to participate exclusively in a single sport have increased dramatically, and youth athletes' parents, sports clubs, and national sporting organizations have embraced the belief that early sport specialization and high-intensity training at a young age are required to reach full athletic potential.<sup>7,28</sup> This belief is perpetuated in the face of the recognized risks of early sport specialization<sup>12</sup> and overtraining, particularly for adolescents during rapid growth.<sup>34,37</sup>

The purpose of this study was to follow female youth soccer players ages 12 to 15 years to identify the number and rate of overuse injuries, describe the anatomic location and type of injury, and evaluate contributing risk factors, including lower extremity muscle strength, joint hypermobility, valgus knee alignment, and amount of playing time for soccer and other sports. We hypothesized that hypermobile joints, weak lower extremity muscle strength, significant valgus knee alignment, and high amounts of participation time in soccer and other sports would be associated with increased risk of overuse injuries.

## METHODS

We performed a prospective cohort study, enrolling 351 female youth soccer players ages 12 to 15 years to evaluate risk factors, including joint hypermobility, hip and knee muscle strength, and jump biomechanics, that are associated with overuse injuries. Lacking a gold standard for overuse injury and drawing on the recommendations of Roos and Marshall,<sup>31</sup> we defined an overuse injury as lower extremity pain, without a clear inciting event, that impaired or limited soccer activities for 2 weeks or more. We choose a minimum of 2 weeks of symptoms in an effort to capture injuries with a component of repetitive microtrauma and to avoid labeling self-limiting soreness as injury.

Among the 4 youth soccer clubs in the Puget Sound region of Washington State, we randomly selected 36 of 72 elite (select and premier) outdoor teams by having a study staff member blindly select from a container the team names listed on separate slips of paper. Of the 36 teams we contacted, 33 (91.7%) agreed to participate, and we recruited 83.2% (351/422) of their players. The top 2 teams in each age group were designated "premier level" and the next level teams were designated "select level" by the soccer clubs. Eight teams were enrolled during the 2008-2009, 2009-2010, and 2010-2011 seasons and 9 teams during the 2011-2012 season, for a total of 20 premier and 13 select teams. The season lasted 1 full year beginning with tryouts in the spring. We followed each team for at least 1 season and 6 teams for 2 seasons, which is the longest any single

team participated. We had complete follow-up on 92.3% of players. All players provided assent, and their parents provided informed consent. This study was approved by the University of Washington Institutional Review Board.

## Joint Hypermobility and Muscle Strength

At the start of the season, the height and weight of all players were measured, and they completed a written survey regarding their age, race, ethnicity, length of soccer career, and prior history of soccer-related injuries resulting in loss of playing time. In addition, players were measured for joint hypermobility with the Beighton scale,<sup>1</sup> hip and knee muscle strength, and a standardized drop-jump test. All the evaluations were performed at the University of Washington Sports Medicine Clinic. We employed 9 experienced physical therapists (PTs) and provided them with detailed written and hands-on instructions for assessing all the physical measurements. All subjects were free of injury at the time of their assessments. For hip strength, the PTs used a Chatillon handheld dynamometer (Ametek Test and Calibration Equipment), using the break technique with standardized positioning to measure hip flexor, extensor, abductor, adductor, and external rotation strength in newton meters. Each test was performed 3 times, and the values were averaged for analysis. For knee strength, the PTs used a Biodex Pro 3 dynamometer (Biodex Medical Systems) to measure concentric hamstring and quadriceps strength in newton meters at an angular speed of 180 deg/s. Each subject performed a standardized warm-up of the right leg consisting of 3 submaximal concentric contractions, followed by 10 maximal-effort repetitions at 180 deg/s, as per the protocol established by Biodex. The largest value of the quadriceps and the hamstrings measurements recorded during the repetitions was used as the maximal strength value. The subject rested for 60 seconds, and the testing procedure was repeated on the left leg.

## Drop-Jump Test

The PTs instructed each player on the drop-jump test procedure using the Sportsmetrics<sup>17</sup> standardized video analysis technique. The Sportsmetrics analysis consists of a video camera that records the testing procedure and is positioned 12 feet from a 31-cm-tall box, a calibrating placard positioned next to the box, and software that analyzes the data. All subjects wore tight-fitting Lycra shorts and low-cut athletic shoes. The PT used double-sided tape to attach reflective markers to each subject at the left and right greater trochanter, the center of the patella, the lateral malleolus, and the right lateral knee. After the PT demonstrated the jumping technique, the subject stepped on the box facing the video camera, turned 90° to her left with her hands on her hips, and hyperextended her knees. The subject turned to face the camera and jumped straight down off the box, landed, and immediately went into a maximum-height vertical jump while the PT videotaped the procedure. After completion of all baseline assessments for the season, our lead PT (L.S.) reviewed all videotapes and captured still images of (1) prelanding, defined as the subject's

toes just touching the ground; (2) landing, defined as the subject in the deepest point of the landing (when the lowest point was reached by the marker on the patella); and (3) takeoff, defined as the subject taking off into the jump, the still image immediately following the landing image. Each player performed the drop-jump test 3 times during the baseline assessment. The PT loaded each of these pictures into the Sportsmetrics software. The hips were defined by the lateral trochanter markers, the knees by the midpatella markers, and the ankles by the lateral malleolus markers. The PT placed the computer cursor on the right and left lateral trochanter, the midpatella, and the lateral malleolus markers, and the software used these markers to calculate the distance between the hips, knees, and ankles using the calibrating placard as a reference point. The average of the 3 drop-jump test results was recorded.

### Injury Surveillance System

We implemented a validated injury surveillance system<sup>32</sup> to identify all overuse injuries occurring during the soccer season. Injuries to the groin, hip, thigh, knee, lower leg, ankle, or foot were included in lower extremity injuries. All parents were required to complete an email survey weekly indicating whether an overuse injury occurred. The email system sent an automated reminder after 2 days of nonresponse, and study staff telephoned all email nonresponders and obtained the information. Study personnel performed a telephone interview with each injured player within 1 week of the injury and collected data about the anatomic location and characteristics of the overuse injury; the problems causing limited soccer play, including pain, weakness, giving way, and concern about making the injury worse; and who evaluated the injured player. Players were interviewed weekly until the injury resolved and full participation resumed. At the final interview, we obtained the date of return to play. Our sports medicine physician assigned a diagnosis after reviewing all interview data and any available medical records. If the diagnosis was in question, the player was offered a free clinical evaluation as well as any required imaging. The weekly internet survey collected the number of athletic exposure hours (AEH) each soccer player spent in practice as well as the number of practices per week. Trained parent volunteers on each team collected the number of game minutes for each player using a game timing sheet. We received timing data for 96% of games.

### Nested Case-Control Study

In addition to our prospective cohort study of risk factors measured at the start of the soccer season, we also performed a case-control study that was nested within our existing cohort to evaluate time-dependent risk factors associated with overuse injury. A case was defined as a soccer player who experienced lower extremity pain, without a clear inciting event, that impaired or limited soccer activities for 2 weeks or more; the reference time for cases was the 2 weeks during the time the player experienced pain with soccer activities. A control was defined as a girl playing in a given week without injury. We used slightly

different terms in reporting descriptive statistics for case and control subjects. Cases were designated as *injuries*, but controls were designated as *player-weeks*, since a control girl would have been selected from a given week of play. Controls were randomly selected every week from all injury-free girls who played that week. Also, to appropriately balance the cumulative number of controls and the cumulative number of overuse injuries, the number of controls selected from a given week took into account the cumulative number of previously selected controls in the study up to that week.

We conducted a telephone interview with each case and control subject within a median time of 3.0 days. The time-dependent risk factors we evaluated in our nested case-control study included usual position played in the month prior to injury or reference time, practicing soccer on one's own in the week prior to injury or reference time, playing on another soccer team in the week prior to injury or reference time, participating on another sports team in the month prior to injury or reference time, and participating in other physical activities. The usual position played was categorized as goalie, defender, midfielder, or forward. The other sports teams we asked about included basketball, volleyball, and track. The other physical activities reported by the girls included golfing, skiing, gymnastics, waterskiing, running, weight lifting, bicycling, aerobics or Pilates, and swimming for 30 minutes or more per week. All time-dependent risk factors were assessed at the time of each case and control interview.

### Statistical Analysis

We calculated the overall rate of lower extremity overuse injuries, the rate of first-time lower extremity overuse injuries, the rate of repeat lower extremity overuse injuries, and the rate of knee overuse injuries, with 95% confidence intervals (CIs), using the counts of each injury as the numerator and the number of AEHs as the denominator. We used percentages to describe the anatomic location, the laterality, and the diagnosis of the injuries as well as the causes of limitations in play and the persons assessing the injury. We compared soccer players with and without overuse injuries based on age, race, ethnicity, level of play, years playing soccer, and prior acute injury.

We evaluated the association between the risk factors assessed at the start of the soccer season and the incidence of lower extremity as well as knee overuse injury using Poisson regression estimated by the generalized estimating equations with the AR1 correlation structure. This modeling strategy was used to estimate the relative risk (RR) and 95% CI and adjusted for clustering by team. The natural logarithm of the number of hours in the season was used as an offset in the regression to account for the amount of playing time for each individual player.

For the Beighton score, we dichotomized the score into 0-4, indicating normal mobility, and  $\geq 5$ , indicating hypermobility.<sup>2</sup> We assessed muscle strength at the hip and knee as a continuous measure per 1 standard deviation (SD). For lower extremity alignment during the drop-jump test, the Sportsmetrics software calculated the separation in

centimeters between each player's hips, knees, and ankles, and we then calculated the normalized knee separation (NKS) as the knee separation divided by the hip separation multiplied by 100. A value of 100 represents no valgus and a value of 0 (no space between knees) represents maximal valgus alignment. We dichotomized the NKS as  $\leq 10$ th percentile (most extreme knee valgus appearance) and  $> 10$ th percentile using the cumulative distribution of NKS from all our soccer players. Because each player performed the drop-jump test 3 times on the baseline assessment day, we averaged the 3 measurements of NKS that were obtained at prelanding, landing, and takeoff. We evaluated the association between the time-dependent risk factors measured in the nested case-control study using survey-weighted logistic regression. For cases, the weight equaled unity (1.0), and for controls it equaled the inverse of the proportion of controls who were selected in each week among the controls who were eligible to be selected for the week. The results of the logistic regression analysis are presented as odds ratios (ORs). All statistical analyses were performed using R, version 2.15.0 (The R Foundation for Statistical Computing).

## RESULTS

Among our 351 subjects, we found 83 lower extremity overuse injuries for a rate of 1.9 per 1000 AEH (95% CI, 1.5-2.4). Of these, 67 were first-time injuries for a rate of 1.7 per 1000 AEH (95% CI, 1.4-2.2). The rate of repeat lower extremity overuse injuries (3.4/1000 AEH [95% CI, 2.1-5.6]) was higher than the incidence rate. The most common overuse injury of the lower extremity was knee injury, with 38 knee injuries for a rate of 0.9 per 1000 AEH (95% CI, 0.6-1.2). Overuse injuries were most likely to be right-sided (37.0%) or bilateral (34.6%), with the most common diagnoses including tendinitis (42.0%), patellofemoral pain syndrome (21.0%), and Osgood-Schlatter disease (13.6%) (Table 1). Tendinitis entails pain directly over any tendon with tenderness, Osgood-Schlatter disease involves pain and tenderness directly over the tibial tubercle, and patellofemoral pain syndrome describes pain around the patella without tenderness directly over the quadriceps or patellar tendons or tibial tubercle. Half of players (50.6%) reported that no one evaluated their injury, and one-third (32.1%) reported they were evaluated by a medical provider. Players limited their participation in soccer because of pain (96.3%), concern about making the injury worse (66.7%), weakness (45.7%), and the joint giving way (40.7%).

We found no statistically significant differences between players with and without overuse injuries regarding age, race, level of play, years playing soccer, or prior acute injury (Table 2).

We found that NKS on landing that was in the  $\leq 10$ th percentile (most valgus appearing) was associated with a 2.24-fold increased risk (95% CI, 1.20-4.19) of lower extremity overuse injury compared with the combined higher percentiles (Table 3). NKS on landing that was in the  $\leq 10$ th percentile was associated with a 3.2-fold increased risk (95% CI, 1.52-6.71) of knee injury. For overuse knee injury, 1-SD increase in hamstring strength was associated with a

TABLE 1  
Characteristics of Lower Extremity Overuse Injuries  
Among Female Youth Soccer Players, 2008-2012 (n = 81<sup>a</sup>)

Injury Characteristic	No. (%)
Lower extremity region	
Hip	15 (18.6)
Groin	1 (1.2)
Thigh	4 (4.9)
Knee	38 (46.9)
Lower leg	7 (8.6)
Foot	8 (9.9)
Ankle	8 (9.9)
Laterality	
Right	30 (37.0)
Left	23 (28.4)
Both	28 (34.6)
Injury diagnosis	
Tendinitis	34 (42.0)
Patellofemoral pain syndrome	17 (21.0)
Osgood-Schlatter disease	11 (13.6)
Periostitis	6 (7.4)
Muscle strain	3 (3.7)
Stress fracture	2 (2.5)
Other	8 (9.8)
Person evaluating the injury <sup>b</sup>	
No one	41 (50.6)
Medical provider	26 (32.1)
Parent	17 (21.0)
Coach	8 (9.9)
Factors limiting ability to play <sup>b</sup>	
Pain	78 (96.3)
Concern about making injury worse	54 (66.7)
Weakness	37 (45.7)
Injured area gives way	33 (40.7)
Decreased range of motion	37 (30.9)
Swelling	13 (16.0)

<sup>a</sup>Two overuse cases had missing injury information.

<sup>b</sup>Numbers may add to more than the total because players were allowed to select  $> 1$  response.

35% decreased risk (RR, 0.65; 95% CI, 0.46-0.91) and 1-SD increase in quadriceps strength was associated with a 30% decreased risk (RR, 0.70; 95% CI, 0.50-0.98). For hip strength, 1-SD increase in hip flexor strength was associated with a 28% decreased risk (RR, 0.72; 95% CI, 0.51-1.00) and 1-SD increase in external rotation strength was associated with a 35% decreased risk (RR, 0.65; 95% CI, 0.46-0.91) of overuse knee injury. We found no statistically significant association between joint hypermobility and risk of lower extremity or knee overuse injury.

Our evaluation of time-varying risk factors (using the OR as the risk measure) showed that players who participated in other physical activities had a 50% decreased risk (OR = 0.50; 95% CI, 0.27-0.86) of lower extremity overuse injury and a 61% decreased risk (OR = 0.39; 95% CI, 0.15-0.81) of knee overuse injury (Table 4). Players who played on another soccer team in the prior week had a 2.5-fold increased risk (95% CI, 1.08-5.35) of knee overuse injury. Among the case subjects, 25% reported playing on another soccer team compared with 17% of the control subjects. We

**TABLE 2**  
Study Characteristics of Female Youth Soccer Players With and Without Overuse Injuries, 2008-2012<sup>a</sup>

	Players With Overuse Injury (n = 83)	Controls (n = 70)
Age		
12 y	18.5	24.6
13 y	35.8	43.0
14 y	34.6	24.0
15 y	11.1	8.4
Race		
White	82.8	85.3
Black	1.2	0
Asian/Pacific Islander	7.4	7.9
Multiracial	8.6	5.8
Hispanic	7.4	3.9
Team level		
Select	45.7	47.2
Premier	54.3	52.8
Years playing soccer		
2-5	17.6	11.9
6-7	41.2	45.1
8-9	30.0	38.0
10-12	11.2	5.0
Prior acute soccer injury	70.4	58.4

<sup>a</sup>Values are expressed as percentages.

**TABLE 3**  
Prospectively Measured Risk Factors for Lower Extremity and Knee Overuse Injuries Among Female Youth Soccer Players, 2008-2012<sup>a</sup>

Risk Factor	Lower Extremity Overuse Injury	Knee Overuse Injury
Joint hypermobility		
Beighton score 0-4	1.0 (reference)	1.0 (reference)
Beighton score ≥5	0.66 (0.31-1.39)	0.68 (0.23-2.02)
Muscle strength		
Hamstring strength 180° per 1 SD	1.00 (0.78-1.28)	0.65 (0.46-0.91)
Quadriceps strength 180° per 1 SD	1.08 (0.83-1.39)	0.70 (0.50-0.98)
Hip flexor per 1 SD	1.02 (0.81-1.29)	0.72 (0.51-1.00)
Hip extensor per 1 SD	1.04 (0.81-1.32)	0.80 (0.54-1.20)
Hip abduction per 1 SD	1.03 (0.82-1.30)	0.79 (0.54-1.15)
Hip adduction per 1 SD	1.13 (0.89-1.43)	1.06 (0.72-1.56)
Hip external rotation per 1 SD	0.97 (0.79-1.19)	0.65 (0.46-0.91)
NKS during drop-jump test		
≤10th percentile vs combined higher percentiles		
Prelanding	1.78 (0.93-3.38)	2.05 (0.92-4.58)
Landing	2.24 (1.20-4.19)	3.20 (1.52-6.71)
Takeoff	1.20 (0.55-2.62)	1.92 (0.84-4.37)

<sup>a</sup>Values are expressed as relative risk (95% CI). NKS, normalized knee separation ( $[knee\ separation / hip\ separation] \times 100$ ).

**TABLE 4**  
Time-Varying Risk Factors for Lower Extremity and Knee Overuse Injuries, 2008-2012<sup>a</sup>

Risk Factor	Lower Extremity Overuse Injury	Knee Overuse Injury
Usual position played in prior month		
Goalie		
No	1.00	1.00
Yes	1.09 (0.44-2.56)	0.66 (0.01-2.29)
Defender		
No	1.00	1.00
Yes	1.01 (0.55-1.82)	1.64 (0.69-3.66)
Forward		
No	1.00	1.00
Yes	0.80 (0.40-1.39)	0.74 (0.23-1.72)
Midfielder		
No	1.00	1.00
Yes	0.98 (0.57-1.71)	0.95 (0.49-2.00)
Practiced soccer on own in prior week		
No	1.00	1.00
Yes	1.18 (0.62-2.07)	1.22 (0.54-2.57)
Played on another soccer team in prior week		
No	1.00	1.00
Yes	1.55 (0.77-2.84)	2.46 (1.08-5.35)
Participated in another sports team in previous month <sup>b</sup>		
No	1.00	1.00
Yes	1.32 (0.78-2.61)	1.88 (0.86-5.66)
Participated in other physical activities <sup>c</sup>		
No	1.00	1.00
Yes	0.50 (0.27-0.86)	0.39 (0.15-0.81)

<sup>a</sup>Values are expressed as odds ratio (95% CI).

<sup>b</sup>Sports teams included basketball, volleyball, and track.

<sup>c</sup>Physical activities included golf, skiing, gymnastics, waterskiing, running, weight lifting, bicycling, aerobics, Pilates, swimming, or other activities.

found no statistically significant association between position played in the past month, practicing soccer on one's own, or participation on another sports team and risk of lower extremity or knee overuse injury.

## DISCUSSION

We found that the incidence rate for first-time lower extremity overuse injuries was 1.7 per 1000 AEH (95% CI, 1.4-2.2), the rate of repeat injuries was 3.4 per 1000 AEH (95% CI, 2.1-5.6), and the total rate was 1.9 per 1000 AEH (95% CI, 1.5-2.4). Calculating athletic exposure hours to establish a rate for overuse injuries is complicated because by definition, the injuries occur secondary to cumulative trauma, some of which may occur during activities other than the primary sport being assessed. In calculating rates, we counted only those injuries occurring with the team being studied and we limited athletic exposure hours

to practice and games for those teams. A minority of the players played soccer on other teams. Accurately accounting for all athletic exposure hours and injuries outside club soccer was not possible or desirable because our goal was to calculate a rate for club soccer only. Non-club soccer and other outside physical activity certainly could have contributed to some of the overuse injuries.

Knee injuries accounted for nearly half (47%) of the total injuries. Just over half of the players sought no evaluation for their injury. Decreased knee separation distance (more valgus appearance) was associated with increased risk of knee injury. Increased quadriceps, hamstring, and hip flexor and external rotator strength was associated with a decreased risk of knee injury. Playing on more than one soccer team increased the risk of knee injury, and participating in other physical activities decreased the risk of total lower extremity and knee injuries.

Most of the soccer literature reports that acute injuries are more common, with overuse injuries comprising 10% to 40% of total injuries.<sup>5,30,33,35</sup> Our overuse injury rate of 1.9 per 1000 AEH is similar to rates reported in several other studies. Jacobson and Tegner<sup>11</sup> evaluated injuries in elite adult female soccer players and found an overuse rate of 1.3 per 1000 AEH, with knee injuries comprising the majority of injuries. Malina<sup>18</sup> studied 9- to 16-year-old boys and found that the rate of training injuries was 1.44 per 1000 AEH, with overuse accounting for the majority of training injuries. Le Gall et al,<sup>16</sup> studying female soccer players age 15 to 19 years, reported a traumatic injury rate of 5.5 per 1000 AEH and an overuse injury rate of 0.9 per 1000 AEH, with the highest injury rate for the players younger than 15 years. In 2016, Junge et al<sup>13</sup> reported athletic exposures, not hours, from a range of sports, including soccer in 8- to 15-year-old boys and girls, and found that overuse knee injuries comprised 85% of the total, with a rate of 5.4 per 1000 AEs.

Unlike studies of adult players, many studies addressing peripubertal athletes<sup>13,18</sup> report that the majority of injuries are from overuse, since both skeletal immaturity and rapid growth are risk factors for overuse injuries. Malina<sup>18</sup> found that boys with skeletal age lagging behind chronological age were at greatest risk of overuse injury. Van der Sluis et al<sup>37</sup> found that elite boys had a higher than 4-fold increase risk of overuse injury during the year before and the year of peak height velocity, corresponding to ages of 13.5 to 14.5 years. Le Gall et al,<sup>17</sup> in a 10-year study of youth players aged 14 to 16 years, found that osteochondrosis was more common in the youngest players. Female sex may also be a risk factor for overuse injuries in adolescence. Stracciolini et al,<sup>34</sup> evaluating the effects of patient sex and growth on pediatric hip injuries, found that boys had more injuries as children, but during puberty the injury proportion for girls exceeded that of boys, and girls had a higher proportion of overuse injuries.

We found that more than half of our players were not evaluated for their overuse injuries by a parent, coach, or medical provider. Clarsen et al<sup>3</sup> compared overuse injuries in elite Norwegian athletes that were reported to their coach or PT during training sessions versus those injuries that were reported using a weekly email questionnaire and

found that the email questionnaire captured 10-fold more overuse injuries. In the study by Le Gall et al,<sup>17</sup> injuries were documented by an on-site physician, likely improving diagnostic accuracy while missing injuries for which medical attention was not sought. Because overuse injuries lack a "responsible mechanism," their onset is less likely to be observed by coaches or medical staff than an acute injury, so the reporting method and injury ascertainment are more challenging. Our findings and those by Clarsen et al<sup>3</sup> argue for expanding overuse injury surveillance systems to include some method of self-reporting, so that the injuries analyzed are not limited to only those that reach the attention of an athletic trainer or team physician. Beyond the ramifications of nonreporting on injury surveillance, it is concerning that parents sought medical care only 32% of the time, despite being aware that an injury had occurred. There are many possible explanations for this finding that go beyond the scope of the data collected for this study. Insurance issues, time pressures for parents and youth, lack of confidence in health care providers to assist with sports injuries, fear of being held out of play, and societal pressure to play through pain likely all contribute. Future research should examine possible barriers to seeking medical care for overuse injuries among youth athletes and their parents.

We found that both strength and knee alignment contributed to risk of overuse injuries. Greater strength in the hamstrings, quadriceps, hip flexors, and hip external rotators was associated with fewer overuse knee injuries. Meta-analyses in adults show that increased quadriceps and hip external rotation strength is associated with less patellofemoral pain.<sup>15,27</sup> Fewer studies have been conducted in adolescents, but Nakase et al<sup>22</sup> found that less knee extension strength as well as muscle tightness and greater weight increased the risk for Osgood-Schlatter disease, which represented 13.6% of our total injuries. Hamstring strength deficits are not as clearly associated with anterior knee pain but are believed to contribute to acute knee injury, specifically anterior cruciate ligament (ACL) tears.<sup>29</sup> While we cannot prove causation, our finding that greater hip, quadriceps, and hamstring strength is associated with fewer overuse knee injuries in this specific population may be useful in the development of conditioning programs to lower the risk.

We also found that the risk of both knee and total lower extremity overuse injury was increased in players in the  $\leq 10$ th percentile of knee-hip separation distance (more valgus appearance) compared with those in the combined higher percentiles. Debate is ongoing regarding the precise risk factors for acute knee injury specifically in female athletes.<sup>4,8,10,25</sup> Valgus knee alignment is considered a risk factor for ACL injury, and training programs designed to decrease valgus alignment and modify other risk factors can decrease the risk of ACL injury.<sup>24</sup> Increased knee valgus is also associated with increased risk of overuse-related anterior knee pain in 13-year-old female basketball players.<sup>20</sup> Warm-up programs to correct valgus alignment through plyometrics and other exercises that emphasize proper technique<sup>24</sup> are encouraged to reduce the risk of acute knee injuries, and such programs may play a role in reducing overuse knee injuries in our

population based on the association between valgus knee alignment and injury identified in this study.

Our finding that playing on more than one soccer team increased the risk for overuse knee injuries is not surprising, and this finding has been reported previously in studies specifically addressing youth athletes. Increased training time and match play time resulted in more overuse injuries among youth boys in Manchester United's Academy.<sup>18</sup> Junge et al<sup>13</sup> found, in children age 8 to 15 years, that overuse injuries increased in those training more than twice a week. The period in the competitive season is also correlated with overuse injuries in youth and adults, with a number of studies finding more overuse injuries in the early season or preseason.<sup>5,11,17,23,38</sup> The seemingly contradictory findings that both volume of training and the start of the season are overuse risk factors suggest that a balance exists between being sufficiently trained to develop the strength needed to reduce risk of overuse injury while also incorporating sufficient rest to allow recovery from micro-trauma that leads to overuse injury.

We found that participating in basketball, volleyball, and track did not increase the risk of overuse injuries, while participation in other sports and recreational activities actually decreased the risk for all lower extremity injuries by 50% and the risk for knee injuries by 61%. This finding—demonstrating increased risk of overuse injury though single-sport participation on multiple teams, but injury protection through simultaneous participation in other sports and recreational activities—is unique, to our knowledge. The risk of overuse injury through early sport specialization has been demonstrated. Myer et al<sup>21</sup> in a clinical review found that quitting all sports to focus on one sport at a young age increased the risk of injury and burnout. Jayanthi et al,<sup>12</sup> who conducted a case-control study of male and female teenagers across multiple sports and controlled for hours of participation, found that sport specialization was an independent risk factor for serious overuse injury. Hall et al<sup>9</sup> found in female soccer, volleyball, and basketball athletes that early sport specialization increased the risk for overuse knee diagnoses. Our prospective study specifically addressing female soccer players is consistent with these findings, but our additional finding that participation in a wider range of physical activity decreased overuse injury risk is unique and further supports recommendations that children avoid early sport specialization for both psychological and physical reasons.<sup>9,21</sup>

Our study had several limitations. Although our rate of overuse injuries is similar to those reported in prior studies, our players may have underreported these types of injuries because the definition of overuse injury and the requirement for pain to persist for 2 or more weeks differed from the definition of traumatic injury, the focus of most players and coaches. Results may have been affected by recall bias, since players with overuse injuries may have been more likely to remember or report participation in other physical activities or participation on other soccer teams in the weeks prior to the onset of injury compared with players without an overuse injury. We performed all interviews with control and case subjects within a median of 3 days of the reference or injury date to decrease this bias. Without

multivariate analysis, independent predictors of injury cannot be determined. Last, we were not able to quantify the number of hours of participation on another soccer team or in other physical activities. Future studies should address overuse injuries for this at-risk and relatively understudied age group, consider including injury self-reporting method, and evaluate the ability of training programs to modify proposed injury risk factors and, more important, decrease the rate of overuse injury.

In conclusion, we found that overuse injuries in adolescent female soccer players are common, primarily affect the knee, and are more likely to occur in those players with weak hips, quadriceps, and hamstrings and those with low knee-hip separation distance. Overuse injuries are also more likely in those playing on more than one soccer team but less likely for those participating in other physical activities. These findings offer opportunities to prevent overuse injuries in this population by developing training programs that address strength and biomechanics, exercising caution with regard to participation on multiple teams in the same sport, and encouraging a wider range of physical activity.

## REFERENCES

1. Baxter-Jones A, Maffulli N, Helms P. Low injury rates in elite athletes. *Arch Dis Child*. 1993;68(1):130-132.
2. Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. *Ann Rheum Dis*. 1973;32(5):413-418.
3. Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire. *Br J Sports Med*. 2013;47:495-502.
4. Dallinga JM, Benjaminse A, Lemmink KA. Which screening tools can predict injury to the lower extremities in team sports? A systematic review. *Sports Med*. 2012;42(9):791-815.
5. Engstrom B, Johansson C, Tornkvist H. Soccer injuries among elite female players. *Am J Sports Med*. 1991;19(4):372-375.
6. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med*. 2006;40(3):193-201.
7. Gladwell M. *Outliers: The Story of Success*. New York, NY: Little, Brown; 2008.
8. Goetschius J, Smith HC, Vacek PM, et al. Application of a clinic-based algorithm as a tool to identify female athletes at risk for anterior cruciate ligament injury: a prospective cohort study with a nested, matched case-control analysis. *Am J Sports Med*. 2012;40(9):1978-1984.
9. Hall R, Barber Foss K, Hewett TE, Myer GD. Sport specialization's association with an increased risk of developing anterior knee pain in adolescent female athletes. *J Sport Rehabil*. 2015;24(1):31-35.
10. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *Am J Sports Med*. 1999;27(6):699-706.
11. Jacobson I, Tegner Y. Injuries among Swedish female elite football players: a prospective population study. *Scand J Med Sci Sports*. 2007;17(1):84-91.
12. Jayanthi NA, LaBella CR, Fischer D, Pasulka J, Dugas LR. Sports-specialized intensive training and the risk of injury in young athletes: a clinical case-control study. *Am J Sports Med*. 2015;43(4):794-801.
13. Junge T, Runge L, Juul-Kristensen B, Wedderkopp N. Risk factors for knee injuries in children 8 to 15 years: the CHAMPS Study DK. *Med Sci Sports Exerc*. 2016;48(4):655-662.

14. Koutures C, Gregory A. Injuries in youth soccer. *Pediatrics*. 2010;125(2):410-414.
15. Lankhorst NE, Bierma-Zeinstra SM, van Middelkoop M. Factors associated with patellofemoral pain syndrome: a systematic review. *Br J Sports Med*. 2013;47(4):193-206.
16. Le Gall F, Carling C, Reilly T. Injuries in young elite female soccer players: an 8-season prospective study. *Am J Sports Med*. 2008;36(2):276-284.
17. Le Gall F, Carling C, Reilly T, Vandewalle H, Church J, Rochcongar P. Incidence of injuries in elite French youth soccer players: a 10-season study. *Am J Sports Med*. 2006;34(6):928-938.
18. Malina RM. Maturity status and injury risk in youth soccer players. *Clin J Sport Med*. 2010;20(2):132.
19. Merkel D. Youth sport: positive and negative impact on young athletes. *Open Access J Sports Med*. 2013;4:151-160.
20. Myer GD, Ford KR, Di Stasi SL, Barber Foss KD, Micheli LJ, Hewett TE. High knee abduction moments are common risk factors for patellofemoral pain (PFP) and anterior cruciate ligament (ACL) injury in girls: is PFP itself a predictor for subsequent ACL injury? *Br J Sports Med*. 2015;49(2):118-122.
21. Myer GD, Jayanthi N, DiFiori JP, et al. Sports specialization, part II: alternative solutions to early sport specialization in youth athletes. *Sports Health*. 2016;8(1):65-73.
22. Nakase J, Goshima K, Numata H, Oshima T, Takata Y, Tsuchiya H. Precise risk factors for Osgood-Schlatter disease. *Arch Orthop Trauma Surg*. 2015;135(9):1277-1281.
23. Noya Salces J, Gómez-Carmona PM, Gracia-Marco L, Moliner-Urdiales D, Sillero-Quintana M. Epidemiology of injuries in First Division Spanish football. *J Sports Sci*. 2014;32(13):1263-1270.
24. Noyes FR, Barber-Westin SD. Neuromuscular retraining intervention programs: do they reduce noncontact anterior cruciate ligament injury rates in adolescent female athletes? *Arthroscopy*. 2014;30(2):245-255.
25. Noyes FR, Barber-Westin SD, Fleckenstein C, Walsh C, West J. The drop-jump screening test: difference in lower limb control by gender and effect of neuromuscular training in female athletes. *Am J Sports Med*. 2005;33(2):197-207.
26. Orava S, Puranen J. Exertion injuries in adolescent athletes. *Br J Sports Med*. 1978;12(1):4-10.
27. Pappas E, Wong-Tom WM. Prospective predictors of patellofemoral pain syndrome: a systematic review with meta-analysis. *Sports Health*. 2012;4(2):115-120.
28. Read PJ, Oliver JL, De Ste Croix MB, Myer GD, Lloyd RS. The scientific foundations and associated injury risks of early soccer specialisation. *J Sports Sci*. 2016;34(24):2295-2302.
29. Renstrom P, Ljungqvist A, Arendt E, et al. Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. *Br J Sports Med*. 2008;42(6):394-412.
30. Ristolainen L, Heinonen A, Turunen H, et al. Type of sport is related to injury profile: a study on cross country skiers, swimmers, long-distance runners and soccer players. A retrospective 12-month study. *Scand J Med Sci Sports*. 2010;20(3):384-393.
31. Roos KG, Marshall SW. Definition and usage of the term "overuse injury" in the US high school and collegiate sport epidemiology literature: a systematic review. *Sports Med*. 2014;44(3):405-421.
32. Schiff MA, Mack CD, Polissar NL, Levy MR, Dow SP, O'Kane JW. Soccer injuries in female youth players: comparison of injury surveillance by certified athletic trainers and internet. *J Athl Train*. 2010;45(3):238-242.
33. Soderman K, Adolphson J, Lorentzon R, Alfredson H. Injuries in adolescent female players in European football: a prospective study over one outdoor soccer season. *Scand J Med Sci Sports*. 2001;11(5):299-304.
34. Stracciolini A, Yen YM, d'Hemecourt PA, Lewis CL, Sugimoto D. Sex and growth effect on pediatric hip injuries presenting to sports medicine clinic. *J Pediatr Orthop B*. 2016;25(4):315-321.
35. Tegnander A, Olsen OE, Moholdt TT, Engebretsen L, Bahr R. Injuries in Norwegian female elite soccer: a prospective one-season cohort study. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(2):194-198.
36. US Youth Soccer. Key statistics. [http://www.usyouthsoccer.org/media\\_kit/keystatistics/](http://www.usyouthsoccer.org/media_kit/keystatistics/). Accessed August 10, 2016.
37. van der Sluis A, Elferink-Gemser MT, Brink MS, Visscher C. Importance of peak height velocity timing in terms of injuries in talented soccer players. *Int J Sports Med*. 2015;36(4):327-332.
38. Woods C, Hawkins R, Hulse M, Hodson A. The Football Association Medical Research Programme: an audit of injuries in professional football-analysis of preseason injuries. *Br J Sports Med*. 2002;36(6):436-441; discussion 441.