Association Between Foot Type and Lower Extremity Injuries: Systematic Literature Review With Meta-analysis

The human foot is often classified into 3 structural categories: high, normal, and low arch, based on its anatomical alignment and the height of the medial longitudinal arch. Classification in these 3 categories is typically based on cutoff values determined from the distribution of data (standard deviations or percentiles) from measurements taken on a large population. The interest in such classification is the belief that nonneutral foot morphology, such as a high or low arch (flatfoot), may lead to less than optimal foot function and be associated with the development of lower extremity and low back injuries.

A review of the literature provides conflicting evidence on the potential relationship between foot type and lower extremity injuries. Although a number of published reports have found no relationships between nonneutral foot types and lower extremity injuries, the authors of a recent systematic review concluded that both high- and low-arch foot types were associated with running-related injuries. The results of this systematic review, which did not include a meta-analysis and effect-size estimates, contrast those of a few qualitative reviews that failed to demonstrate a relationship between foot type and future lower extremity injuries. This lack of consensus in the literature could be attributed, in part, to the variation in the operational definition of foot type among investigators.

A large variety of methods have been developed to classify the foot based on structure and alignment. These methods include anatomic, radiographic, and anthropometric measures. Most of these techniques are used to assess the foot posture index, which is derived from the foot posture index equation (FPI = (100 - C) / (200 - C) x 100). The FPI is calculated by subtracting the angle between the first metatarsal and the fifth metatarsal from 180 degrees and dividing the result by 200. The resulting value is then multiplied by 100 to obtain a percentage.

The FPI reflects the alignment of the foot and can be used to identify individuals with nonneutral foot types. This classification system has been used in a number of studies to evaluate the relationship between foot type and lower extremity injuries. However, the results of these studies have been inconsistent, with some finding a significant association between nonneutral foot types and lower extremity injuries and others reporting no significant association.

The present study was conducted to identify relevant articles. The search included comparative cross-sectional, case-control, and prospective studies that reported qualitative/quantitative associations between nonneutral foot types and lower extremity and back injuries. Quality of the selected studies was evaluated, and data synthesis for the level of association between nonneutral foot types and lower extremity injuries was conducted using a continuous scale, measurements of lateral calcaneal pitch angle (SMD, 1.92; 95% CI: 1.44, 2.39; P<.0001), lateral talocalcaneal angle (SMD, 1.36; 95% CI: 0.93, 1.80; P<.0001), and navicular height (SMD, 0.34; 95% CI: 0.16, 0.52; P<.001) showed significant effect sizes in identifying high-arch foot, whereas the navicular drop test (SMD, 0.45; 95% CI: 0.03, 0.87; P<.05) and relaxed calcaneal stance position (SMD, 0.49; 95% CI: 0.01, 0.97; P<.05) displayed significant effect sizes in identifying flatfoot. Subgroup analyses revealed no significant associations for children with flatfoot, cross-sectional studies, or prospective studies on high arch.

The results of this study suggest that nonneutral foot types are associated with lower extremity injuries, but the strength of this relationship is low. Although the foot posture index and visual/physical examination showed significance, they are qualitative measures. Radiographic and navicular height measurements can delineate high-arch foot effectively, with only anthropometric measures accurately classifying flatfoot.
TABLE 1

<table>
<thead>
<tr>
<th>Questions</th>
<th>Score 1</th>
<th>Score 0</th>
<th>Interrater Agreement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Were the inclusion/exclusion criteria clearly defined?</td>
<td>Definition of recruited population</td>
<td>Missing or unclear inclusion/exclusion criteria</td>
<td>0.75</td>
</tr>
<tr>
<td>and rationale for recruitment are clear and appropriate</td>
<td>n=100</td>
<td>n=100</td>
<td>0.92</td>
</tr>
<tr>
<td>2. Were there sufficient subject numbers included?</td>
<td>Well-conducted case-control (retrospective) or prospective cohort studies</td>
<td>Cross-sectional studies, case-control (retrospective) or prospective cohort studies with a high risk of confounding or bias</td>
<td>0.89</td>
</tr>
<tr>
<td>3. Was the level of evidence high?</td>
<td>Comparable in at least 3 of the following attributes: age, sex, physical characteristics, activity type and level</td>
<td>Data were unavailable for comparison, or comparable in less than 3 of the attributes described</td>
<td>0.79</td>
</tr>
<tr>
<td>4. Were the injury and control groups comparable?</td>
<td>Quantitative or semi-quantitative measures (eg, joint angles, arch height, scoring of observable signs, and physical assessment)</td>
<td>Missing or unclear classification methods, or qualitative measure (eg, purely descriptive observation and physical assessment)</td>
<td>0.96</td>
</tr>
<tr>
<td>5. Were methods/measures used to classify foot type appropriate?</td>
<td>Confounding factors were adjusted either through matching or multivariate regression analysis</td>
<td>Confounding factors were not adjusted</td>
<td>0.73</td>
</tr>
<tr>
<td>6. Were appropriate statistical methods used?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Values are kappa (P<.001).

Methods for Methodological Quality Assessment of the Studies and Interrater Agreement for the Rating of Each Question (56 Studies Included for Full-Text Review)

No search limits were used for the year, language of publication, and study design in an effort to include as many published articles as possible for initial screening. The first reviewer (J.W.K.T.) performed the search after agreement on the search terms (APPENDIX A, available at www.jospt.org) was reached with the second reviewer (P.W.K.).

Study Selection
Based on the title and abstract, potentially relevant articles for inclusion in the review were selected if they met the following criteria: published in English; cross-sectional, case-control (retrospective), or prospective cohort study design; subjects either screened or assessed in weight bearing or self-reported foot structure/type at the beginning of the study; comparative groups identified at the beginning of the study; injuries to the lower extremities or low back reported for the study period; and qualitative or quantitative analyses reporting on the association between foot structure/type and injuries to the lower extremities or low back.

The search process was conducted independently by 2 reviewers (J.W.K.T. and P.W.K.). Any disagreement over the selected abstracts for inclusion for full-text review was deliberated and resolved through mutual consent. Subsequently, full-text papers were retrieved for further review, and the reference lists of those articles were also searched by hand for relevant publications. The reviewers also performed searches in Google Scholar using key words.

Methodological Quality Assessment and Data Extraction
The methodological quality of each selected full-text article was assessed independently by both reviewers (J.W.K.T. and P.W.K.), and scoring was based on 6 criteria modified from those proposed by Barnes et al (TABLE I). Both reviewers initially agreed on the definition of the 6 methodological quality assessment questions before undertaking scoring of the

Data Sources and Search

Based on the current literature, it remains unclear whether foot type is associated with the incidence of lower extremity injuries. A secondary purpose was to identify the most appropriate method of assessing foot type. The results of this literature review may help clinical practice by determining the value of assessing foot type and implementing preventive and/or corrective strategies based on such evaluation. Also, they may inform clinical practice and research efforts by potentially identifying the best methods to assess foot type.

METHODS

Data Sources and Search

A search for titles and abstracts in PubMed (1966-2011), Embase (1974-2011), CINAHL (1983-2011), SPORTDiscus (1985-2011), and ProQuest Dissertations and Theses electronic databases was performed on April 11, 2012. The search process was conducted independently by 2 reviewers (J.W.K.T. and P.W.K.). Any disagreement over the selected abstracts for inclusion for full-text review was deliberated and resolved through mutual consent. Subsequently, full-text papers were retrieved for further review, and the reference lists of those articles were also searched by hand for relevant publications. The reviewers also performed searches in Google Scholar using key words.
TABLE 2

Foot-Structure Categories With Corresponding Terms and Definitions Used in the Included Studies

<table>
<thead>
<tr>
<th>Foot-Structure Category</th>
<th>Terms</th>
<th>Definition Based on Weight-Bearing Assessment</th>
</tr>
</thead>
</table>
| High arch               | High arch, pes cavus, cavus foot, varus foot, supinated, underpronating, nonpronating | Quantitative measures of the medial longitudinal arch that are:  
  - Less than or equal to or greater than or equal to (dependent on direction of variable) 1.15, or 2 standard deviations from the sample mean; or  
  - Less than or equal to the lowest or greater than or equal to the highest (dependent on direction of variable) 20th percentile or tertile of sample population; or  
  - Less than the 25th percentile of sample population; or  
  - Cutoff as determined by Kolmogorov-Smirnov 2-sample test  
  - Midfoot width divided by heel width equals 0  
  - Examiner is able to insert fingers fully under the arch |
| Neutral foot            | Neutral, normal, middle, average arch, rectus, normal foot | Quantitative measures of the medial longitudinal arch that are:  
  - Within ±1.15, or 2 standard deviations from the sample mean; or  
  - Within the middle tertile; or  
  - Within the 20th to 80th percentiles  
  - Midfoot width divided by heel width, less than or equal to middle tertile (except zero) |
| Flatfoot                | Flatfoot, pes planus, flat arch, planus feet, low arch, valgus foot | Quantitative measures of the medial longitudinal arch that are:  
  - Less than or equal to or greater than or equal to (dependent on direction of variable) 1.15, or 2 standard deviations from the sample mean; or  
  - Less than or equal to the lowest or greater than or equal to the highest (dependent on direction of variable) 20th percentile or tertile of sample population; or  
  - Greater than the 75th percentile; or  
  - Cutoff as determined by Kolmogorov-Smirnov 2-sample test  
  - Midfoot width divided by heel width, highest tertile  
  - Width of central zone of the foot is at least half the forefoot width |

selected studies. Any disagreement on scoring was resolved by discussion and consensus on a score for each question. The maximum possible score for methodological quality was 6, and only studies that scored 3 or greater were included in the literature review and meta-analysis. A standardized form was used for data extraction of selected studies, which included information on study design, participants, the country where the study was conducted, methods to establish foot classification, and lower extremity and low back injuries considered in the study. In addition, data extraction included reporting the results of the study along with their related statistical significance. For studies that did not perform any statistical analysis, the results were considered nonsignificant.

Data Synthesis and Analysis

Interrater agreement for each methodological quality assessment question was assessed with kappa statistics (SPSS; SPSS Inc, Chicago, IL). Meta-analysis was performed with RevMan software (Nordic Cochrane Centre, Copenhagen, Denmark), instituted by the Cochrane Collaboration for systematic review and meta-analysis. Odds ratios (ORs) and corresponding 95% confidence intervals (CIs) were computed by entering raw dichotomous counts of lower extremity or low back injuries (outcome) for each categorical foot-type classification (exposure) into the software. Among the included studies, foot type was classified based on various descriptions; therefore, the reviewers adopted common foot-type definitions, with neutral foot (NF) as the reference category, and high arch (HA) and flatfoot (FF) as the nonneutral foot-type categories (TABLE 2).

Pooled estimates of the ORs for the relevant studies were analyzed with Mantel-Haenszel test statistics, a method of computing ORs when combining studies. For studies that reported the severity of lower extremity or low back injuries based on continuous measures (eg, visual analog pain scale) between the NF and HA or FF groups, results were pooled using standardized mean differences (SMDs) and corresponding 95% CIs to account for the different outcome scales used among studies. Positive effect sizes indicated that the injuries were associated with subjects in the HA or FF group, whereas negative effect sizes indicated that injuries were associated with subjects in the NF group.

Similarly, we used SMD to pool studies that reported foot-type assessment as continuous measures when comparing the subjects who had lower extremity or low back injuries to those in the control group. In these cases, because foot assessment was an outcome on a continuous scale, we used positive effects to indicate a tendency toward nonneutral foot type for subjects in the injury group. Negative effects indicated a tendency toward an NF foot type for subjects in the control group. Whenever insufficient outcome data were encountered, we contacted the corresponding authors for further clarification.

Four subgroup analyses were conducted. First, pooled data were analyzed separately for HA and FF foot types, so that the association between each foot type and lower extremity or low back injuries could be ascertained. Second, as the intention of this study was also to determine the most appropriate method to classify or assess foot type, a subgroup analysis was conducted across different categorical and continuous measures utilized for foot-type classification or assessment. Third, the association between foot type and lower extremity injuries was analyzed for subjects younger than
18 years of age and those 18 years of age or older. This analysis was performed because the pediatric population may display different findings compared to adults, based on a still-developing and perhaps more adaptable foot. Finally, a subgroup analysis was also performed based on different study designs (prospective cohort, case-control [retrospective], and cross-sectional).

A random-effects model (DerSimonian-Laird) was applied to account for the different groups of subjects recruited and the variety of reported lower extremity and low back injuries. Random errors were added to the estimates, so that within- and between-study variances could be adjusted and weighted. Tests of heterogeneity among studies were also performed with the chi-square test, and the extent of the heterogeneity was assessed with the I² statistic at the outcome level.

To assess for publication bias, a funnel plot was generated, in which asymmetry of the plot was interpreted to suggest that positive studies with larger samples tend to be published more readily than studies with smaller samples and/or negative (lack of statistical significance) results. For all analyses, significance was set at P<.05.

RESULTS

Study Selection

Figure 1 displays the flow diagram of the search strategy and review process, consistent with the PRISMA guidelines. The electronic search of the online databases identified 4525 potentially relevant manuscripts. Based on the review of the abstracts, 70 articles were retained for full-text retrieval and analysis. An additional 25 potentially relevant articles were identified after hand searching the reference lists of the 70 selected full-text articles and through Google Scholar. Of these 25 articles, following examination of the abstracts, 14 were selected for full-text retrieval and review. After removing 28 duplicate articles, assessment and scoring of methodological quality were performed on 56 full-text articles that met all inclusion criteria for the review. Of these 56 articles, 34 met the criterion for a minimum methodological quality score of 3 or greater. A qualitative synthesis of these studies was performed, with information provided in Appendix B (available at www.jospt.org).

The level of agreement between the 2 reviewers for each question used to assess the methodological quality of the studies ranged from good to excellent (κ = 0.73-0.96, P<.001).

Study Populations

The subject populations of the 34 studies that were qualitative-
FIGURE 2. Forest plot of odds ratio between nonneutral foot type and lower extremity injuries. Favors HA or FF refers to the specific studies that showed an association between injuries and nonneutral foot type. Favors NF refers to the specific studies that showed an association between injuries and neutral foot type.

Table 1. Study (Foot Type/Injury)

<table>
<thead>
<tr>
<th>Study (Foot Type/Injury)</th>
<th>Odds Ratio (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td>1.1%</td>
<td></td>
</tr>
<tr>
<td>1.2%</td>
<td></td>
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<tr>
<td>1.3%</td>
<td></td>
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<tr>
<td>1.4%</td>
<td></td>
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<tr>
<td>1.5%</td>
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<td>1.6%</td>
<td></td>
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<tr>
<td>1.7%</td>
<td></td>
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<tr>
<td>1.8%</td>
<td></td>
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<tr>
<td>1.9%</td>
<td></td>
</tr>
<tr>
<td>2.0%</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: AI, arch index; AT, Achilles tendinitis; BF, barefoot; F, female; FF, flatfoot; FPI, foot posture index; HA, high arch; IS, inshoe; ITS, iliotibial band syndrome; KP, knee pain; LBP, low back pain; LE, lower extremity; M, male; NF, neutral foot; NHI, navicular height index; PF, plantar fasciitis; Pr, prospective; RCSP, relaxed calcaneal stance position; Re, case-control; SI, Staheli index; VI, valgus index.
participants was less than 18 years \cite{23,26,50} in 24 studies the mean age was 18 or greater \cite{2,13,10,12,11,33,34,36,41,46,52,53,56,63,72,79,81,97,101,104} and in 6 studies the age of the participants was not specified \cite{24,47,49,65,68}. In addition to low back pain \cite{10,44} the following lower extremity clinical injuries were considered: stress fracture,\cite{38,46,48,52,98} \textbf{knee pain},\cite{23,49,50} anterior cruciate ligament injury,\cite{2} \textbf{foot pain},\cite{3,11,63,70} \textbf{heel pain},\cite{41} \textbf{plantar fasciitis},\cite{43} \textbf{ankle sprain},\cite{46} \textbf{Achilles tendinitis} or \textbf{rupture},\cite{23} \textbf{iliotibial band syndrome},\cite{26} \textbf{patellofemoral syndrome},\cite{46} \textbf{blisters},\cite{47} \textbf{medial tibial stress syndrome},\cite{7,104} \textbf{foot accident or rheumatoid arthritis},\cite{1} \textbf{hip or knee pain} or \textbf{general osteoarthritis}, and \textbf{general lower extremity injury or pain}.\cite{12,13,22,24,26,36,97,101}

**Foot-Classification Methods**

Methods of foot-type classification or as-

<table>
<thead>
<tr>
<th>Study (Foot Type/Injury)</th>
<th>Weight</th>
<th>Odds Ratio (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaufman et al\cite{AI-AI-BF, ITS}</td>
<td>1.0%</td>
<td>1.24 (0.47, 3.27)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-AI-BF, PF}</td>
<td>1.0%</td>
<td>0.78 (0.28, 2.17)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-AI-BF, SF}</td>
<td>0.8%</td>
<td>1.76 (0.57, 5.45)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-AI-IS, AT}</td>
<td>0.7%</td>
<td>1.25 (0.37, 4.23)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-AI-IS, ITS}</td>
<td>1.0%</td>
<td>1.50 (0.55, 4.11)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-AI-IS, PF}</td>
<td>0.8%</td>
<td>1.02 (0.32, 3.27)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-AI-IS, SF}</td>
<td>0.8%</td>
<td>1.89 (0.61, 5.85)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-NHI, AT}</td>
<td>0.8%</td>
<td>1.64 (0.52, 5.13)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-NHI, ITS}</td>
<td>1.4%</td>
<td>1.26 (0.55, 2.89)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-NHI, PF}</td>
<td>1.3%</td>
<td>1.32 (0.56, 3.12)</td>
</tr>
<tr>
<td>Kaufman et al\cite{AI-NHI, SF}</td>
<td>1.6%</td>
<td>0.73 (0.35, 1.54)</td>
</tr>
<tr>
<td>Knapp et al\cite{FF}</td>
<td>2.3%</td>
<td>1.84 (1.01, 3.35)</td>
</tr>
<tr>
<td>Knapp et al\cite{FF}</td>
<td>1.7%</td>
<td>1.46 (0.71, 2.98)</td>
</tr>
<tr>
<td>Korpelin et al\cite{FF}</td>
<td>0.2%</td>
<td>3.43 (0.26, 45.03)</td>
</tr>
<tr>
<td>Korpelin et al\cite{FF}</td>
<td>0.3%</td>
<td>5.14 (0.81, 32.77)</td>
</tr>
<tr>
<td>Kosashvili et al\cite{FF-KP}</td>
<td>76%</td>
<td>1.15 (0.50, 2.64)</td>
</tr>
<tr>
<td>Kosashvili et al\cite{FF-LBP}</td>
<td>76%</td>
<td>1.10 (1.02, 1.18)</td>
</tr>
<tr>
<td>Lakstein et al\cite{FF-flexible}</td>
<td>75%</td>
<td>1.11 (1.02, 1.21)</td>
</tr>
<tr>
<td>Lakstein et al\cite{FF-rigid}</td>
<td>5.2%</td>
<td>1.76 (1.34, 2.31)</td>
</tr>
<tr>
<td>Leppilahi et al\cite{FF-RCS}</td>
<td>2.2%</td>
<td>0.77 (0.42, 1.40)</td>
</tr>
<tr>
<td>Leppilahi et al\cite{FF-Si}</td>
<td>0.2%</td>
<td>0.26 (0.03, 2.37)</td>
</tr>
<tr>
<td>Leppilahi et al\cite{FF-RCS}</td>
<td>0.9%</td>
<td>4.29 (1.49, 12.32)</td>
</tr>
<tr>
<td>Leppilahi et al\cite{FF-Si}</td>
<td>2.3%</td>
<td>1.36 (0.75, 2.49)</td>
</tr>
<tr>
<td>Mcunar et al\cite{FF-first year}</td>
<td>1.0%</td>
<td>0.64 (0.24, 1.72)</td>
</tr>
<tr>
<td>Mcunar et al\cite{FF-second year}</td>
<td>1.0%</td>
<td>1.08 (0.39, 3.02)</td>
</tr>
<tr>
<td>Michelson et al\cite{FF}</td>
<td>2.1%</td>
<td>0.76 (0.40, 1.44)</td>
</tr>
<tr>
<td>Paiva de Castro et al\cite{FF-AI-F}</td>
<td>1.9%</td>
<td>0.77 (0.39, 1.51)</td>
</tr>
<tr>
<td>Paiva de Castro et al\cite{FF-AI-M}</td>
<td>1.3%</td>
<td>1.10 (0.46, 2.62)</td>
</tr>
<tr>
<td>Paiva de Castro et al\cite{FF-AI-F}</td>
<td>1.8%</td>
<td>0.61 (0.31, 1.23)</td>
</tr>
<tr>
<td>Paiva de Castro et al\cite{FF-AI-M}</td>
<td>1.4%</td>
<td>1.17 (0.52, 2.62)</td>
</tr>
<tr>
<td>Wang et al\cite{FF}</td>
<td>1.1%</td>
<td>8.05 (3.18, 20.42)</td>
</tr>
<tr>
<td>Yales and White\cite{FF}</td>
<td>1.2%</td>
<td>3.86 (1.60, 9.29)</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>1.23 (1.11, 1.37)</td>
</tr>
</tbody>
</table>

Abbreviations: AI, arch index; AT, Achilles tendinitis; BF, barefoot; F, female; FF, flatfoot; FPI, foot posture index; HA, high arch; IS, inshoe; ITS, iliotibial band syndrome; KP, knee pain; LBP, low back pain; LE, lower extremity; M, male; NF, neutral foot; NHI, navicular height index; PF, plantar fasciitis; Pr, prospective; RCS, relaxed calcaneal stance position; Re, case-control; SF, stress fracture; SI, Staheli index; VI, valgus index. Heterogeneity: $\chi^2 = 134.01$, df = 65, $P = .01%$. Test for overall estimate. $P < .001$. 

**FIGURE 2. (CONTINUED)** Forest plot of odds ratio between nonneutral foot type and lower extremity injuries. Favors HA or FF refers to the specific studies that showed an association between injuries and nonneutral foot type. Favors NF refers to the specific studies that showed an association between injuries and NF type.
**Table 1: Standardized Mean Difference (95% Confidence Interval)**

<table>
<thead>
<tr>
<th>Study (Measure)</th>
<th>Weight</th>
<th>Standardized Mean Difference (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen and Glasoe (NDT)</td>
<td>1.6%</td>
<td>0.67 (0.02, 1.37)</td>
</tr>
<tr>
<td>Bartosik et al (AHI)</td>
<td>1.6%</td>
<td>0.49 (-0.21, 1.19)</td>
</tr>
<tr>
<td>Bartosik et al (CPEI)</td>
<td>1.6%</td>
<td>0.10 (-0.59, 0.79)</td>
</tr>
<tr>
<td>Bartosik et al (VI)</td>
<td>1.6%</td>
<td>0.36 (-0.34, 1.05)</td>
</tr>
<tr>
<td>Bennett et al (NDT)</td>
<td>1.9%</td>
<td>0.90 (0.31, 1.48)</td>
</tr>
<tr>
<td>Bennett et al (RCSP)</td>
<td>2.0%</td>
<td>0.14 (-0.42, 0.69)</td>
</tr>
<tr>
<td>Bennett et al (rearfoot angle)</td>
<td>2.0%</td>
<td>0.29 (-0.27, 0.85)</td>
</tr>
<tr>
<td>Burns et al (FPI-P)</td>
<td>2.6%</td>
<td>0.11 (-0.27, 0.49)</td>
</tr>
<tr>
<td>Burns et al (FPI-Re)</td>
<td>2.7%</td>
<td>0.04 (-0.32, 0.40)</td>
</tr>
<tr>
<td>Burns et al (VI-P)</td>
<td>2.6%</td>
<td>0.10 (-0.28, 0.48)</td>
</tr>
<tr>
<td>Burns et al (VI-Re)</td>
<td>2.7%</td>
<td>0.03 (-0.35, 0.37)</td>
</tr>
<tr>
<td>Cain et al (FPI)</td>
<td>2.2%</td>
<td>0.45 (-0.04, 0.94)</td>
</tr>
<tr>
<td>Evans et al (FPI-L)</td>
<td>3.0%</td>
<td>0.09 (-0.21, 0.39)</td>
</tr>
<tr>
<td>Evans et al (FPI-R)</td>
<td>3.0%</td>
<td>0.08 (-0.21, 0.38)</td>
</tr>
<tr>
<td>Evans et al (NDI-L)</td>
<td>3.0%</td>
<td>0.04 (-0.26, 0.33)</td>
</tr>
<tr>
<td>Evans et al (NDI-R)</td>
<td>3.0%</td>
<td>0.06 (-0.24, 0.35)</td>
</tr>
<tr>
<td>Evans et al (NH-L)</td>
<td>3.0%</td>
<td>0.32 (0.03, 0.62)</td>
</tr>
<tr>
<td>Evans et al (NH-R)</td>
<td>3.0%</td>
<td>0.25 (-0.05, 0.54)</td>
</tr>
<tr>
<td>Evans et al (RCSP-L)</td>
<td>3.0%</td>
<td>0.02 (-0.27, 0.32)</td>
</tr>
<tr>
<td>Evans et al (RCSP-R)</td>
<td>3.0%</td>
<td>0.05 (-0.25, 0.34)</td>
</tr>
</tbody>
</table>

**Abbreviations:** AD, arch drop; AHI, arch height index; AI, arch index; CPEI, center-of-pressure excursion index; F, female; FPI, foot posture index; L, left; LAA, longitudinal arch angle; LCMA, lateral calcaneal pitch angle; LTCA, lateral talocalcaneal angle; LTMA, lateral talo-first metatarsal angle; M, male; NDT, navicular drop test; NF, neutral foot; NHI, navicular height; NHI, navicular height index; OA, osteoarthritis; Pr, prospective; R, right; RCSP, relaxed calcaneal stance position; Re, case-control; VI, valgus index.

**Heterogeneity:** $\chi^2 = 148.31, df = 40, I^2 = 73\%$. Test for overall effect: $P < .00001$.

**FIGURE 3.** Forest plot of standardized mean difference for foot-type assessment method reported as continuous measures between the group of subjects with lower extremity injuries and the control group. Favors injury refers to the specific studies that showed a tendency toward nonneutral foot type in the injury group. Favors control refers to the specific studies that showed a tendency toward neutral foot type in the control group. Figure continues on page 707.

The authors of 1 study did not report standard deviations or standard errors,10 and the authors of 5 other studies did not report data on the number of lower extremity injuries (outcome)11,12,56,72 or the number of participants (sample)3 with each foot type. Of the corresponding authors of these 6 studies with missing data, only 312,56,72 provided the required data when contacted; the remaining 3 studies1,5,10 were excluded from the meta-analysis.

**Meta-analysis**

Of the initial 34 studies selected, 29 were included for meta-analysis. Of these studies, Paiva de Castro et al12 and Evans and Scutter12 reported results for male and female and left and right foot sepa-
rately, Burns et al\textsuperscript{12} incorporated both case-control (retrospective) and prospective study designs, and McManus et al\textsuperscript{56} reported the results of their 2-year prospective study separately for each year. Eleven studies either utilized more than 1 method to categorize foot type\textsuperscript{34,46,53} or assessed the foot using continuous scales,\textsuperscript{5,7,12,26,38,52,79,81} and 4 studies reported on more than 1 lower extremity injury using either a dichotomous outcome\textsuperscript{14,20,41} or a continuous scale.\textsuperscript{54}

In the meta-analysis, to account for all genders, feet (right/left), study designs, low back and lower extremity injuries, and methods of foot-type classification/assessment reported in the included studies, the outcome of each analysis was entered separately as a unique study. Accordingly, because Lakstein and colleagues\textsuperscript{50} classified foot type as either FF flexible or FF rigid, the results of the analysis for each foot-type classification were entered as a study of its own. In total, 66, 41, and 2 study entries were entered for the meta-analyses based on categorical foot-type classification, foot-type assessment using continuous measures, and lower extremity injuries reported as continuous measures, respectively.

**Main Analysis: Pooled Results From All Studies**

The weighted pooled estimates for the results of studies that classified foot type based on distinct categories indicated a significant association (OR = 1.23; 95% CI: 1.11, 1.37; \( \chi^2 = 134.01; I^2 = 51\); \(P < .001\)) between nonneutral foot type (HA and FF) and lower extremity injuries across all foot-type classification methods, with a medium level of heterogeneity\textsuperscript{39} (FIGURE 2). In studies that assessed foot type with continuous measures, the pooled SMD indicated the tendency of nonneutral foot types (SMD, 0.34; 95% CI: 0.22, 0.46; \( \chi^2 = 148.31; I^2 = 73\%; P < .00001\)) (FIGURE 3) to significantly favor the group of subjects presenting with lower extremity injuries. Pooled results of studies re-

### Abbreviations

AD, arch drop; AI, arch index; AHI, arch height index; AI, arch index; CPEI, center-of-pressure excursion index; F, female; FPI, foot posture index; L, left; LAA, longitudinal arch angle; LCRA, lateral calcaneal pitch angle; LTCA, lateral talocalcaneal angle; LTMA, lateral talar first metatarsal angle; M, male; NDT, navicular drop test; NF, neutral foot; NHI, navicular height; NHI, navicular height index; OA, osteoarthritis; Pr, prospective; R, right; RCSP, relaxed calcaneal stance position; Re, case-control; VI, valgus index.

**FIGURE 3. (CONTINUED)** Forest plot of standardized mean difference for foot-type assessment method reported as continuous measures between the group of subjects with lower extremity injuries and the control group. Favors injury refers to the specific studies that showed a tendency toward nonneutral foot type in the injury group. Favors control refers to the specific studies that showed a tendency toward neutral foot type in the control group.
porting lower extremity injuries using continuous scales (visual analog pain scale and Western Ontario and McMaster Universities Osteoarthritis Index) indicated a near-significant effect of foot type, with high heterogeneity that favored FF as being associated with a more severe injury (SMD, 0.56; 95% CI: -0.01, 1.13; \( \chi^2 = 4.62; I^2 = 78\%; P = .05 \) (FIGURE 4).

### Subgroup Analysis: HA and FF

For studies using a classification approach to categorize foot type, the association between nonneutral foot type and injuries remained significant for both FF (OR = 1.23; 95% CI: 1.08, 1.40; \( \chi^2 = 89.36; I^2 = 59\%; P < .01 \)) and HA (OR = 1.31; 95% CI: 1.05, 1.62; \( \chi^2 = 43.78; I^2 = 38\%; P < .05 \)). Foot types when the data were pooled separately, but the extent of heterogeneity between studies for HA was lower (TABLE 3). For the studies assessing foot type using continuous scales, separate subgroup analyses for HA (SMD, 0.35; 95% CI: 0.17, 0.53; \( \chi^2 = 101.24; I^2 = 81\%; P < .001 \)) and FF (SMD, 0.34; 95% CI: 0.19, 0.49; \( \chi^2 = 46.74; I^2 = 57\%; P < .0001 \)) tendencies also indicated significant effects for the group of subjects presenting with lower extremity injuries, but the levels of heterogeneity among studies for HA and FF analyses were high and medium, respectively (TABLE 4). Regardless of the method of foot assessment, the level of association (OR = 1.23) and effect size (SMD, 0.34) linking FF to a greater incidence of lower extremity injuries were highly comparable to those in the primary analyses (OR = 1.23; SMD, 0.34) (TABLES 3 and 4).

### Subgroup Analysis: Methods of Foot Classification/Assessment

Among foot assessment methods using categories for classification of foot type category.
type, the foot posture index showed significant association between nonneutral foot type and injuries, with a low level of heterogeneity among studies (OR = 2.58; 95% CI: 1.33, 5.02; $\chi^2 = 8.21; I^2 = 39\%; P < .01$). Although the methods using visual observation/physical examination also showed a significant association between nonneutral foot type and injuries, the heterogeneity was high (OR = 1.17; 95% CI: 1.06, 1.28; $\chi^2 = 10.94; I^2 = 73\%; P < .01$). The method of foot classification used by Wang et al$^{27}$ also displayed significant association between nonneutral foot type and injuries, but insufficient details on this method were provided in the article (OR = 8.05; 95% CI: 3.18, 20.42; $P < .0001$), and its estimate was much greater in magnitude than that of the main analysis (OR = 8.05 versus 1.23). Studies using visual observation/physical examination had results closest to that of the main analysis (OR = 1.17 versus 1.23).

Among the methods that used a continuous scale to assess HA tendency, only the measures of navicular height (SMD, 0.34; 95% CI: 0.16, 0.52; $\chi^2 = 1.23; I^2 = 0\%; P < .001$), lateral calcaneal pitch angle (SMD, 1.92; 95% CI: 1.44, 2.39; $P < .0001$), and lateral talocalcaneal angle (SMD, 1.36; 95% CI: 0.93, 1.80; $P < .00001$) displayed significant effects in the group of subjects who presented with lower extremity injuries. There was no heterogeneity between studies that measured navicular height. The effect size for studies using navicular height (SMD, 0.34) was highly comparable to that of the main analysis (SMD, 0.34). Among the methods that used a continuous scale to measure FF tendency, significance only occurred for the measurement of the relaxed calcaneal stance position (SMD, 0.49; 95% CI: 0.01, 0.97; $\chi^2 = 18.53; I^2 = 84\%; P < .05$) and navicular drop test (SMD, 0.45; 95% CI: 0.03, 0.87; $\chi^2 = 8.44; I^2 = 64\%; P < .05$), with high and medium heterogeneity observed, respectively. The effect size for studies using the navicular drop test (SMD, 0.45) was closest to that of the main analysis (SMD, 0.34).

### Subgroup Analysis: Age Group of Subjects

The association between nonneutral foot type and lower extremity injuries was significant, with a medium level of heterogeneity for subjects 18 years and older (OR = 1.32; 95% CI: 1.10, 1.57; $\chi^2 = 105.89; I^2 = 53\%; P < .01$), with the OR...
being greater than that reported for the main analysis (1.32 versus 1.23).

Subgroup analysis of subjects younger than 18 years of age in studies that used continuous measures for foot assessment exhibited significant effect only for HA tendency, with no heterogeneity (SMD, 0.16; 95% CI: 0.04, 0.27; \( \chi^2 = 4.51; I^2 = 0\%\); \( P < .01 \)). The effect was smaller than that of the main analysis (SMD, 0.16 versus 0.34). Those aged 18 years and older showed significant effects for both HA (SMD, 0.46; 95% CI: 0.18, 0.73; \( \chi^2 = 83.18; I^2 = 86\%\); \( P < .01 \)) and FF (SMD, 0.37; 95% CI: 0.19, 0.55; \( \chi^2 = 36.10; I^2 = 58\%\); \( P < .0001 \)) tendencies, with high and medium heterogeneity, respectively. The effect was closest to that of the main analysis for FF tendency (SMD, 0.37 versus 0.34), in contrast to the effect for HA tendency (SMD, 0.46), which was larger.

**Subgroup Analysis: Study Design**

In studies that classified foot type based on distinct categories, only prospective (OR = 1.26; 95% CI: 1.04, 1.52; \( \chi^2 = 62.56; I^2 = 33\%\); \( P < .05 \)) and case-control (OR = 1.21; 95% CI: 1.08, 1.36; \( \chi^2 = 23.63; I^2 = 58\%\); \( P < .01 \)) study designs displayed a significant association between nonneutral foot type and injuries, with low and medium heterogeneity, respectively. The association of case-control studies was closer to that of the main analysis but of a slightly lower magnitude (OR = 1.21 versus 1.23) when compared with prospective studies (OR = 1.26 versus 1.23).

The prospective study design using continuous measures for foot assessment displayed a significant effect, with a low heterogeneity in the group of subjects presenting with lower extremity injuries for FF tendency only (SMD, 0.49; 95% CI: 0.25, 0.73; \( \chi^2 = 4.41; I^2 = 9\%\); \( P < .0001 \)). Significant effects were observed for both HA (SMD, 0.40; 95% CI: 0.14, 0.67; \( \chi^2 = 82.11; I^2 = 85\%\); \( P < .01 \)) and FF (SMD, 0.34; 95% CI: 0.09, 0.58; \( \chi^2 = 32.41; I^2 = 72\%\); \( P < .01 \)) tendencies, with high and near-high heterogeneity, respectively, in the group of subjects presenting with lower extremity injuries for case-control designs. No significant effects for either foot-type tendency were seen for cross-sectional studies. The effect of FF for prospective studies was much greater in magnitude than the main analysis (SMD, 0.49 versus 0.34), whereas that of case-control studies was highly comparable to the main analysis (SMD, 0.34). The effect of HA for case-control studies was greater in magnitude than the main analysis (SMD, 0.40 versus 0.34).

**Funnel Plots**

The funnel plot of foot-type assessment using categorical classification was “hollow” at its lower center half (FIGURE 5A). This suggests that publication might be biased toward smaller studies that only showed significant associations between either HA and FF (OR > 1) or NF (OR < 1) with lower extremity injuries, and not those reporting similar associations between groups (OR = 1). Funnel plots of foot-type assessment and lower extremity injuries reported as continuous measures displayed symmetrical distribution graphically, which suggests that publication bias is unlikely (FIGURES 5B and 5C).

**DISCUSSION**

To our knowledge, this is the first meta-analysis to report pooled data on the relationship between foot type and lower extremity injuries. Our primary findings indicate that an HA or FF foot type, when compared to an NF foot type, is associated with lower extremity injuries (OR = 1.23). This statistically significant but low OR estimate remained significant for both FF and HA foot types when data for each foot type were analyzed separately. Similarly, in studies that reported foot assessment as continuous measures, both HA and FF foot types exhibited significant effect sizes in subjects who presented with lower extremity injuries.

The low but statistically significant level of association between foot type and lower extremity injuries found in our study is in contrast to the qualitative reviews of studies performed among the athletic population.\(^{6,20,70}\) These studies concluded that there is a lack of evidence to support the relationship between foot type and lower-limb injuries. Also in contrast to our review, Barnes and col-

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**FIGURE 5.** Funnel plot to assess publication bias for (A) all 66 study entries that reported categorical foot-type classification, (B) all 41 study entries that reported foot-type assessment as continuous measures between nonneutral and flatfoot categories. Abbreviations: OR, odds ratio; SE, standard error; SMD, standardized mean difference.
leagues' concluded in their systematic review that foot type was not a definitive risk factor for tibial stress injuries. Carvalho and colleagues, on the other hand, suggested that HA and FF foot types were associated with running-related injuries.

This review also attempted to provide an evidence-based inquiry into the most acceptable and accurate method of assessing the foot type associated with lower extremity injuries. We believe that a foot-type assessment method that takes into account the associated presentation of lower extremity injuries is clinically meaningful. Barnes and colleagues suggested that quantitative measures of foot alignment were superior to a qualitative classification, based on better reliability. Our review seems to favor the use of the foot posture index and visual/physical examination. However, it is possible that observer subjectivity and bias may undermine the accuracy of these qualitative or, at most, semi-quantitative appraisal tools. The clinical method of choice for foot classification should be validated against the gold standard; however, to our knowledge, there is currently no study that has validated a visual-assessment approach with radiographic measurements.

The foot posture index assessment tool aims to overcome the inconsistencies of qualitative visual methods. When using the foot posture index, investigators visually assess the foot based on 6 or 8 criteria, each rated on a 5-point (-2 to +2) Likert scale. Although normative data sets have recently been collated for individuals aged 3 to 17 years, there is still no consensus on limits to define various foot types. Because the foot posture index is based on visual observation, it has the same limitations as other qualitative methods. In addition, the elevated OR from the pooled estimates using the foot posture index must be interpreted with caution (foot posture index OR = 2.58 versus pooled OR = 1.23). Therefore, it may not be a suitable method for foot screening at this stage. Although the method suggested by Wang et al was significant, its highly elevated estimate (OR = 8.05) compared to the main analysis (OR = 1.23) must also be interpreted with caution.

From our results, radiographic measurements appear best to detect whether HA foot type is associated with lower extremity injuries. Both the lateral calcaneal pitch angle and lateral talocalcaneal angle measurements provided the greatest effect sizes in the group of subjects presenting with lower extremity injuries when compared with the control group. Our findings support the common opinion of using radiographic measurements as the gold standard when assessing foot structure. However, as mentioned in the introduction, a method using ionizing radiation is not a viable routine clinical or screening option.

Our analysis showed that navicular height can be an alternative continuous measure of foot type when assessing HA tendency. Although navicular height can be measured with high intrarater (intraclass correlation coefficient [ICC] = 0.90) and interrater (ICC = 0.74) agreement, the technique has not been validated against radiographic measures.

When assessing FF tendency on a continuous scale, both the navicular drop test and relaxed calcaneal stance position showed significant effect sizes in the group presenting with lower extremity injuries. The intrarater reliability of the navicular drop test was previously reported, with ICCs between 0.61 and 0.79, whereas interrater reliability ranged from 0.46 to 0.83. The validity agreement of the navicular drop test with values calculated from radiographs through radio-opaque markers affixed on the surface anatomical landmarks had good Pearson correlation coefficients (between 0.61 and 0.89). As for relaxed calcaneal stance position, an earlier critical review of the literature concluded that this method was inherently unreliable and invalid. The ICCs for intrarater and interrater agreement for this measurement varied between 0.39 and 0.98, but skin measurement of this angle correlated well (left, r = 0.74; right, r = 0.82) with radiographic measurement when radio-opaque markers were applied.

These anthropometric measures (navicular height, navicular drop test, and relaxed calcaneal stance position) may be good alternatives to radiographic measurements but are often time consuming, involving skin markings and laborious manual measurements. As a result, they may not be applicable for large-scale population screening. Furthermore, they are static measurements, which may not reflect the dynamic loads on the foot during locomotion.

Nonneutral foot type in subjects aged 18 years and older consistently presented with an association with lower extremity injuries, regardless of whether categorical or continuous measures were used. On the other hand, only the HA foot tendency showed significant effect in the group with lower extremity injuries for subjects aged younger than 18 years. It may be that children's feet are still developing, appearing flat and more adaptable to mitigate any impending external factors that might cause injury. Although the estimate provided by categorical foot-type classification in subjects aged younger than 18 years was insignificant (OR = 1.37, P = .16), its proximity to that of subjects aged 18 years and older (OR = 1.32) is worth mentioning, especially because there were only 2 study entries from Lakstein et al. In that study, a cohort of military recruits with a mean age of 17.2 years were assessed. Based on the large sample size (increasing the weight of the analysis) and the mean age of the sample being close to the 18-year mark, it could be argued that the estimate should be interpreted as consistent with those aged 18 years or younger.

Evidently, prospective cohort studies were deemed more powerful than case-control (retrospective) and cross-sectional analyses. Although prospective studies that utilized continuous measures for HA foot-type assessment were not predictive of lower extremity injuries, all
other prospective and case-control studies in this meta-analysis displayed an association with lower extremity injuries. There are several limitations of the present study. First, the search process on the electronic databases was conducted by a single reviewer, which could have biased the results. Second, the demographics of the subjects were such that almost two thirds of them placed extraneous demands of physical activity on their feet, being military personnel and competitive/amateur athletes. Therefore, the results may not be applicable to sedentary populations. In addition, only a few studies included subjects younger than 18 years of age, hence the specific methods reviewed might not be completely applicable to this age group. Furthermore, because the range of lower extremity injuries recorded in our review was so diverse, it is not possible to pinpoint with confidence the kind of injuries associated with either HA or FF. Finally, studies reviewed displayed publication bias toward smaller studies that reported significant results. Nevertheless, our systematic review of pooled estimates and effect sizes provided an evidence-based account of the relationship between nonneutral foot type and lower extremity injuries.

CONCLUSION

Both HA and FF foot types are significantly associated with lower extremity injuries, although the strength of this relationship is low. If foot type was classified categorically, both foot posture index and visual/physical examination methods showed the strongest associations, but these methods are semiquantitative and qualitative techniques. For foot assessment using a continuous scale, radiographic measurements of the lateral calcaneal pitch angle and lateral talocalcaneal angle, followed by navicular height measurements, were effective in identifying HA foot type, and the relaxed calcaneal stance position and navicular drop test were effective in identifying the FF type.

KEY POINTS

FINDINGS: There is a significant association of HA and FF foot types with lower extremity injuries, but the strength of this relationship is low. The foot posture index and visual/physical examination foot-classification methods showed significant associations. Lateral calcaneal pitch angle, lateral talocalcaneal angle, and navicular height measurements displayed significant effect sizes in identifying the HA foot type. The navicular drop test and relaxed calcaneal stance position displayed significant effect sizes for the FF foot type.

IMPLICATIONS: When classifying foot type using categorical methods, the foot posture index and visual/physical examination showed significant associations with lower extremity conditions. For foot assessment using continuous measures, radiographic measurements of the lateral calcaneal pitch angle and lateral talocalcaneal angle, followed by navicular height measurements, are effective in identifying HA foot type, and the navicular drop test and relaxed calcaneal stance position are effective in identifying the FF foot type.

CAUTION: The studies reviewed predominantly recruited adults older than 18 years of age and individuals who placed increased activity on their feet, such as athletes and military personnel. Therefore, the results must be interpreted with caution when applied to children or sedentary adult populations.

ACKNOWLEDGEMENTS: The authors would like to thank all corresponding investigators who replied to our requests and provided us with the required data.

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42. Igibigbi PS, Msamati BC, Shariff MB. Arch index as a predictor of arch height. Foot Ankle Int. 1997;18:668-674.
57. Menz HB, Munteanu SE. Validity of 3 clinical
### APPENDIX A

**TERMS ENTERED INTO THE ELECTRONIC SEARCH PROCESS**


(d) a AND b AND c

### APPENDIX B

**EXTRACTION OF LOWER EXTREMITY INJURY DATA REPORTED IN THE STUDIES THAT SCORED 3 OR MORE POINTS ON THE SCALE FOR METHODOLOGICAL QUALITY ASSESSMENT**

<table>
<thead>
<tr>
<th>Study</th>
<th>Quality Score</th>
<th>Study Design</th>
<th>Population</th>
<th>Country of Study</th>
<th>Method of Foot Assessment</th>
<th>Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdel-Fattah et al</td>
<td>6</td>
<td>Case-control (retrospective)</td>
<td>Army recruits: flatfoot, n = 104, 100% male, 19.1 ± 0.4 y; control, n = 412, 100% male, 19.3 ± 0.9 y</td>
<td>Saudi Arabia</td>
<td>Denis grade</td>
<td>Flatfoot nonsignificant association with: history of foot accident, OR = 0.79 (invalid CI); history of rheumatoid arthritis, OR = 1.72 (0.35, 2.53)</td>
<td>Number of subjects with history of foot accident and rheumatoid arthritis in each foot-type group was not reported</td>
</tr>
<tr>
<td>Allen and Glasoe</td>
<td>3</td>
<td>Cross-sectional</td>
<td>Adults (age matched): ACL injury, n = 18, 67% male, 29.9 ± 9.5 y; control, n = 16, 29.9 ± 8.6 y</td>
<td>United States</td>
<td>Navicular drop test</td>
<td>Significant difference in navicular drop test between ACL injury and control group</td>
<td>Navicular drop test: ACL injury, 10.5 ± 4.0 mm; control, 8.1 ± 2.8 mm</td>
</tr>
<tr>
<td>Badlissi et al</td>
<td>3</td>
<td>Cross-sectional</td>
<td>Elderly adults: n = 784, 43% male, 74.5 y</td>
<td>United States</td>
<td>Physical examination</td>
<td>High arch association with foot pain, adjusted OR = 4.0 (1.4, 11.3); flatfoot nonsignificant association with foot pain, adjusted OR = 1.6 (0.9, 2.9)</td>
<td>Total number of subjects in each foot-type group was not reported</td>
</tr>
<tr>
<td>Bartosik et al</td>
<td>3</td>
<td>Cross-sectional</td>
<td>Medial tibial stress syndrome, n = 34, 36% male, 22.7 ± 3.8 y; control, n = 19, 53% male, 24.8 ± 4.1 y</td>
<td>United States</td>
<td>Valgus index, arch height index, center-of-pressure excursion index</td>
<td>Nonsignificant difference in valgus index, arch height index, and center-of-pressure excursion index between medial tibial stress syndrome and control group; flatfoot (center-of-pressure excursion index) nonsignificant association with medial tibial stress syndrome</td>
<td>Valgus index: medial tibial stress syndrome, 12.72 ± 5.29°; control, 10.79 ± 5.27°</td>
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<tr>
<th>Study</th>
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<th>Results</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>Bennett et al(^1)</td>
<td>6</td>
<td>Prospective</td>
<td>High school runners, n = 125 (250 limbs); medial tibial stress syndrome, n = 15 (25 limbs), 13% male; control, n = 21 (25 limbs) randomly selected from original cohort, 62% male, 15.7 ± 1.5 y</td>
<td>United States</td>
<td>Navicular drop test, relaxed calcaneal stance position, rearfoot angle</td>
<td>Flatfoot (navicular drop test) logistically regressed with sex to predict medial tibial stress syndrome; risk prediction equation, -3.351 + 2.484 (men/women) + 0.328 (navicular drop test); relaxed calcaneal stance position and rearfoot angle, non-significant association with medial tibial stress syndrome</td>
<td>Navicular drop test: medial tibial stress syndrome, 6.8 ± 3.7 mm; control, 1.6 ± 3.3 mm; relaxed calcaneal stance position: medial tibial stress syndrome, 2.8° ± 3.3°; control, 2.2° ± 5.2°. Rearfoot angle: medial tibial stress syndrome, 17.2° ± 5.5°; control, 15.4° ± 6.7°</td>
</tr>
<tr>
<td>Brantingham et al(^2)</td>
<td>3</td>
<td>Cross-sectional</td>
<td>Chronic or recurrent low back pain, n = 100, 32% male, 31.2 y (range, 18-45 y); control, n = 104, 61% male, 28.8 y (range, 18-44 y)</td>
<td>South Africa</td>
<td>Navicular drop test</td>
<td>Significant difference in navicular drop test between low back pain and control group</td>
<td>Navicular drop test (left): low back pain, 4.1 mm; control, 5.7 mm. Navicular drop test (right): low back pain, 3.9 mm; control, 5.6 mm. SD, SE, and CI not reported</td>
</tr>
<tr>
<td>Burns et al(^3)</td>
<td>4</td>
<td>Case-control (retrospective)</td>
<td>Idiopathic high arch, n = 30, 30.6 ± 13.5 y; neurogenic high arch, n = 10, 56.5 ± 18.6 y; neutral foot, n = 30, 31.7 ± 11.1 y</td>
<td>Australia</td>
<td>Foot posture index</td>
<td>Significant difference in number of subjects with foot pain between high arch (60%) and neutral foot (23%)</td>
<td>Foot pain: high arch, 24/40; neutral foot, 7/30</td>
</tr>
<tr>
<td>Burns et al(^4)</td>
<td>4</td>
<td>Case-control (retrospective) and prospective</td>
<td>Triathletes: n = 134, 69% male, 33.7 ± 10.3 y</td>
<td>Australia</td>
<td>Foot posture index, valgus index</td>
<td>Retrospective (preseason): high arch (foot posture index) nonsignificant association with injury, OR = 1.91 (0.65, 5.59); flatfoot (foot posture index) nonsignificant association with injury, OR = 1.04 (0.13, 8.01); high arch (valgus index) nonsignificant association with injury, OR = 1.91 (0.12, 29.84); flatfoot (valgus index) nonsignificant association with injury, OR = 0.48 (0.06, 4.35); nonsignificant difference in foot posture index and valgus index between injured and control group. Prospective (competition season): high arch (foot posture index) associated with injury, OR = 4.30 (1.34, 13.83); flatfoot (foot posture index) nonsignificant association with injury, OR = 0.41 (0.05, 3.29); high arch (valgus index) nonsignificant association with injury, OR = 2.46 (0.16, 38.29); flatfoot (valgus index) nonsignificant association with injury, OR = 0.62 (0.07, 5.32); nonsignificant difference in foot posture index and valgus index between injured and control group.</td>
<td>Prospective injury Foot posture index: high arch, 6/12; neutral foot, 37/111; flatfoot, 2/8 Valgus index: high arch, 1/2; neutral foot, 43/124; flatfoot, 1/5 Foot posture index: injured, 5.2 ± 4.8; control, 5.0 ± 4.3 Valgus index: injured, 10.1 ± 7.2; control, 11.0 ± 8.3</td>
</tr>
</tbody>
</table>

*Foot pain: high arch, 24/40; neutral foot, 7/30*
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<tr>
<th>Study</th>
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<th>Method of Foot Assessment</th>
<th>Results</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>Cain et al&lt;sup&gt;23&lt;/sup&gt;</td>
<td>4</td>
<td>Prospective</td>
<td>Competitive futsal players: n = 76; 100% male, 14.3 ± 1.7 y</td>
<td>Australia</td>
<td>Foot posture index</td>
<td>High arch was linearly regressed with foot posture index scores to predict foot/ankle injury; risk prediction equation, –0.5 – 0.313 (foot posture index score)</td>
<td>Foot posture index: injured (n = 24), 2.8 ± 11.3; control (n = 52), 5.8 ± 2.6&lt;sup&gt;‡&lt;/sup&gt;</td>
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<td>Cowan et al&lt;sup&gt;22&lt;/sup&gt;</td>
<td>5</td>
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<td>Infantry trainees: n = 246, 20.3 y</td>
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<td>Navicular height index</td>
<td>High arch associated with lower extremity injury when compared with flatfoot, adjusted OR = 6.12 (2.17, 17.30); neutral foot associated with lower extremity injury when compared with flatfoot, adjusted OR = 2.96 (1.25, 7.04)</td>
<td>Lower extremity injury: high arch, 26/49; neutral foot, 58/148; flatfoot, 11/49</td>
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<td>Navicular height (left) positively associated with growing pains, adjusted OR = 1.09 (0.95, 1.25); nonsignificant difference in navicular height (right), navicular drop test (left and right), relaxed calcaneal stance position (left and right), and foot posture index (left and right) between growing pains and control group</td>
<td>Navicular height (left): pain, 33.93 ± 3.23 mm; control, 32.60 ± 4.63 mm</td>
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<td>Neutral foot category undefined in study; total feet, 3796 Knee pain: high arch, 134/745; neutral foot, 422/1954; flatfoot, 318/1047</td>
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<td>Flatfoot associated with injury, IRR = 1.29 (1.07, 1.56)</td>
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Abbreviations: ACL, anterior cruciate ligament; ANOVA, analysis of variance; CI, confidence interval; IRR, incidence rate ratio; LE, lower extremity; OR, odds ratio; RR, relative risk; SE, standard error; VAS, visual analog scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

\(^*\)Continuous data are mean ± SD.

\(^†\)Computed SD from reported SE.

\(^‡\)Midfoot area defined as middle third of foot, excluding toes.

\(^§\)Midfoot area defined from point between calcaneus and cuboid to point between cuboid and base of metatarsals.