Characteristics of foot structure and footwear associated with hallux valgus: a systematic review

S. E. Nix†‡, B. T. Vicenzino†, N. J. Collins§‖, M. D. Smith†*

†Division of Physiotherapy, School of Health and Rehabilitation Sciences, The University of Queensland, St Lucia QLD 4072, Australia

‡School of Clinical Sciences, Queensland University of Technology, Kelvin Grove QLD 4059, Australia

§Department of Mechanical Engineering, Melbourne School of Engineering, The University of Melbourne, Parkville VIC 3052, Australia

‖Department of Physiotherapy, Melbourne School of Health Sciences, The University of Melbourne, Parkville VIC 3052, Australia

*Address correspondence and reprint requests to: Dr Michelle Smith, School of Health and Rehabilitation Sciences, The University of Queensland, St Lucia QLD 4072, Australia. Ph: +61 7 3365 4523, Fax: +61 7 3365 1622, E-mail: m.smith5@uq.edu.au

Running title: Foot structure in HV: systematic review

Objective: Factors associated with the development of hallux valgus (HV) are multifactorial and remain unclear. The objective of this systematic review and meta-analysis was to investigate characteristics of foot structure and footwear associated with HV.

Design: Electronic databases (Medline, Embase, and CINAHL) were searched to December 2010. Cross-sectional studies with a valid definition of HV and a non-HV comparison group were included. Two independent investigators quality rated all included papers. Effect sizes and 95% confidence intervals (CI) were calculated (standardized mean differences (SMD) for continuous data and risk ratios (RR) for dichotomous data). Where studies were homogeneous, pooling of SMDs was conducted using random effects models.

Results: A total of 37 papers (34 unique studies) were quality rated. After exclusion of studies without reported measurement reliability for associated factors, data were extracted and analysed from 16 studies reporting results for 45 different factors. Significant factors included: greater first intermetatarsal angle (pooled SMD = 1.5, CI: 0.88 to 2.1), longer first metatarsal (pooled SMD = 1.0, CI: 0.48 to 1.6), round first metatarsal head (RR: 3.1 to 5.4), and lateral sesamoid displacement (RR: 5.1 to 5.5). Results for clinical factors (e.g. first ray mobility, pes planus, footwear) were less conclusive regarding their association with HV.

Conclusions: Although conclusions regarding causality cannot be made from cross-sectional studies, this systematic review highlights important factors to monitor in HV assessment and management. Further studies with rigorous methodology are warranted to investigate clinical factors associated with HV.

Key words: Hallux Valgus, Footwear, Foot, Systematic Review

Introduction

Hallux valgus (HV) is a highly prevalent foot deformity estimated to affect 23% of adults and 35.7% of elderly individuals[1]. HV presents a significant individual and public health burden due to the high occurrence of related orthopaedic foot surgery[2], and its association with foot pain[3-7], osteoarthritis (OA) at the first metatarsophalangeal joint (MTPJ)[8], impaired gait patterns[9], poor coordinated stability and an increased risk of falls in older adults[10-13].

While development of HV is believed to be multifactorial, the exact etiology remains unclear. Previous studies have suggested that a number of structural factors may be characteristic of HV, including various radiographic angles, first MTPJ congruency, metatarsal length, metatarsal head shape, sesamoid position, first metatarsocuneiform joint flexibility and pes planus[14-16]. These factors are routinely assessed by orthopaedic surgeons both clinically and radiographically, and are considered by many authors to be significant in the development of HV[17-20]. However, there is a lack of consensus regarding which of these factors, if any, are most significant[21, 22]. In addition to structural factors, current and past footwear habits are widely considered to be important in HV development[23-26]. While this concept often guides clinical practice, recent studies have found conflicting results and no critical analysis of study methodology has been performed[27, 28].

Descriptive literature reviews have previously discussed factors associated with HV[21, 22, 29]; however, no report has systematically evaluated the literature and quantitatively synthesised results from the best available evidence. Therefore, a systematic review and meta-analysis was conducted to investigate the association between HV and characteristics of foot structure, joint flexibility and footwear in individuals with HV compared to controls. The focus of this paper is passive structural factors frequently assessed by orthopaedic specialists. While recent studies have investigated the impact of HV on dynamic gait characteristics[30, 31], these are beyond the scope of the current study. Furthermore, as the association between HV, female sex and increasing age has been previously demonstrated[1], it will not be discussed further. Finally, although HV can be associated with neuromuscular disorders and inflammatory joint disease, individuals without systemic disorders are the focus of this review.

Methods

Search strategy

Electronic databases (Medline, Embase, and CINAHL) were searched by one investigator for all years available up to December 2010, without language restriction. A highly sensitive search strategy was used and has been previously reported in detail[1]. Search terms included subject headings specific to each database, as well as keywords including "hallux valgus," "bunion," and "foot deformity" with truncation and proximity symbols. The search waslimited by a second string of search terms, including synonyms relating to cross-sectional, case-control or prospective study designs, risk factors and associated factors. Reference lists of relevant articles were hand-searched by the same investigator in order to retrieve all available papers.

Study inclusion

Titles and abstracts of all identified records were scanned for eligibility using the screening question: "Does the paper discuss factors associated with HV?" Full-text articles were then retrieved for detailed evaluation according to the following pre-determined inclusion criteria: 1) HV clearly defined (using HV angle or categorization of severity) and assessed using a validated method (weight-bearing radiograph or photograph, finger goniometer, or categorical rating scale); 2) investigated association between HV and foot structure or footwear; 3) investigated individuals of any age without systemic disorders; 4) cross-sectional or longitudinal study design with non-HV comparison group. Translations were obtained for articles published in languages other than English. Assessment of study eligibility was performed by one investigator. Authors were contacted for clarification of study methodology when required.

Quality assessment and risk of bias

Included papers were assessed for methodological quality by two independent raters, with any disagreements resolved by consultation with a third party. Title, journal, and author details were removed to de-identify articles prior to rating. Quality ratings were performed using the Epidemiological Appraisal Instrument (EAI)[32], which has been validated for assessment of observational studies. Thirty-one items from the original EAI were used, after removing items relating to interventions, randomization, follow-up period, or loss to follow-up that were not applicable to cross-sectional studies. Items were scored as "Yes" (score = 2), "Partial" (score = 1), "No" (score = 0), "Unable to determine" (score = 0), or "Not Applicable" (item removed from scoring) and an average score across all items was calculated for each study (range 0 to 2). To assess potential publication bias across included studies, visual inspection of funnel plots was conducted with effect sizes plotted against study quality scores and sample size.

Data management

One investigator recorded the following details for all included papers: publication details (author, year, publication type, country), sample characteristics (sampling frame, inclusion criteria, number of HV cases, number of control subjects, age and sex), and study methodology (study design, examiner details, definition of HV, associated factors investigated, and reliability of measurement methods). Data extraction and further analysis of individual study results was only carried out for studies that reported measurement reliability of the associated factors investigated using statistical methods (reliability coefficients, kappa statistics, or t-tests) or reference to previous literature. This was done to ensure validity of the outcomes of this systematic review. In order to calculate effect sizes, HV and control means and standard deviations (SD) were recorded for continuous variables, and raw counts for dichotomous variables. Associated factors that were reported as categorical variables were collapsed into dichotomous categories for analysis. Subgroups of mild, moderate, and severe HV classified according to the Manchester Scale[33] were collapsed into the following dichotomous groupings: none/mild, or moderate/severe HV[34]. Additional data was requested from authors where means and SDs had not been provided in the original publication.

Statistical methods

Effect sizes and 95% confidence intervals (CI) were calculated using Stata (version 10)[35]. Standardized mean differences (SMD) were calculated for continuous data as the difference between HV and control group means, divided by the pooled standard deviation[36]. Interpretation of SMDs was based on previous guidelines[37]: small effect ≥ 0.2, medium effect ≥ 0.5, large effect ≥ 0.8. Risk ratios (RR) were calculated for dichotomous data by dividing the proportion of subjects with HV in the group with the associated factor present by the proportion of subjects with HV in the group without the associated factor; where HV was considered as the "event" for the purposes of calculating RR[36]. A RR of > 1.0 indicated that HV was more likely to be found in subjects with the associated factor present. Interpretation of RRs was as follows: small effect ≥ 2.0, large effect ≥ 4.0[38]. Effect sizes were considered statistically significant if the 95% CI did not contain zero (SMD) or one (RR). Where studies investigated similar cohorts and associated factors, pooling of SMDs was conducted based on a random effects inverse variance model. Heterogeneity was quantified using chi-squared tests ($p < 0.10$) and the I^2 statistic described by Higgins *et al.*[39], which represents the percentage of total variation across studies due to heterogeneity. Substantial heterogeneity was considered to be represented by I^2 values greater than 75%[36]. Post hoc sensitivity analyses were performed to assess the impact of HV diagnosis method or a juvenile HV sample on pooled effect sizes.

Results

Study selection

A total of 7709 unique records were identified by our search strategy. Figure 1 outlines studies excluded at each stage of the study selection process. The full text of 527 papers was examined, with 30 of these translated into English from other languages (9 German, 4 Chinese, 3 Japanese, 3 Russian, 2 French, 2 Italian, 2 Spanish, 2 Serbo-Croatian, 1 Korean, 1 Polish, and 1 Turkish). Three authors were contacted to clarify whether weight-bearing radiographs were used. One author[40] confirmed that radiographs were taken in weight-bearing; however, two authors did not respond[41, 42] and these papers were subsequently excluded. Thirty-seven papers met the eligibility criteria and underwent quality assessment. Seventeen of these did not report measurement reliability for associated factors and were excluded from further analysis. Data extraction was carried out on the remaining 20 papers. Five authors were contacted for additional data, with three authors able to provide the data requested. One author (of three papers) responded but was unable to provide additional data, and these papers could not be analysed further, leaving 17 papers. No response was received from the fifth author; therefore, only one out of three factors investigated by this study could be analysed. Two papers that reported data from the same sample were given a single study ID. Therefore, data were analysed from 16 unique studies, reporting results for 45 different structural and footwear factors associated with HV. For studies that reported data from left and right feet[43] and men and women separately[28], groups were pooled in order to facilitate comparison with other studies. Table 1 outlines characteristics of the 16 studies included in our analysis, while Table 2 describes the 18 studies (20 papers) excluded from further analysis.

Quality assessment and risk of bias

Inter-rater agreement on the EAI was 82% (204 disagreements out of 1147 quality assessment items rated) across all included studies (37 papers). Individual study results for quality appraisal are shown in Table 3. The majority of studies clearly reported their aims (29/37, 78%) and defined the associated factors investigated (25/37, 68%). Reporting of inclusion criteria and sample characteristics was performed by more than half of the studies (24/37, 65% and 27/37, 73% respectively). Overall, few papers adequately reported statistical methods (5/37, 14%) and less than one-third of studies (11/37, 30%) reported results using effect sizes that could be readily interpreted by the reader. Very few studies reported participation rate (4/37, 11%) or described non-responder characteristics (3/35, 9%), making it difficult to assess the generalizability of study results. Only 16% (6/37) of studies adequately considered confounders such as age and sex by using statistical adjustment techniques or by matching case and control groups. No studies adequately reported sample size calculations or reported any attempt to blind assessors towards group allocation, although, given the nature of HV deformity, blinding assessors is unlikely to be possible in the majority of studies.

Reliability and validity were considered separately for both HV assessment and measurement of associated factors. Regarding validity of HV assessment, 68% (25/37) of studies either used weight-bearing radiographs or reported concurrent validity with a coefficient > 0.7. However, only 57% (21/37) of studies provided a clear definition of HV using angular criteria, and only 38% (14/37) reported reliability for HV angle assessment. Regarding measurement of associated factors, 17 papers made no mention of reliability (thus excluded from further analysis), and seven papers gave insufficient details (i.e. reported reliability for some but not all associated factors investigated, or did not report numerical reliability coefficients). Three papers scored "Partial" indicating that the reliability coefficient for one or more variables was less than 0.7 but greater than 0.4. Therefore, only ten papers (27%) scored "Yes" indicating adequate reliability (coefficient > 0.7) for all associated factors. Substantiating measurement validity for associated factors was quite poor, although we considered weight-bearing radiographs to be the "gold standard" for structural measurements of the foot, and 13 studies (35%) scored "Yes" for this reason.

Regarding potential publication bias, when SMDs for all associated factors included for quantitative analysis were plotted against sample size and study quality scores, resulting funnel plots appeared symmetrical, indicating that publication bias was unlikely to have impacted findings from this review.

Associated factors

Of the 37 studies initially included, twelve studies investigated radiographic factors with acceptable measurement reliability[8, 43-53], while five studies investigated clinical characteristics of foot structure and footwear with sufficient reliability[27, 28, 54-56]. Due to the wide range of associated factors and study methodologies, only a limited number of pooled estimates could be generated by meta-analysis.

Figure 2 presents SMDs (95% CI) for individual studies, as well as pooled estimates for the following radiographic factors: first intermetatarsal angle, metatarsus adductus angle, first metatarsal protrusion distance, and calcaneal inclination angle. Significantly larger first intermetatarsal angles were found in the HV group for all studies that investigated this, with pooled data showing a significant large effect (SMD = 1.58, 95% CI: 0.72 to 2.44). Similarly, all but one study that investigated first metatarsal protrusion distance found increased first metatarsal length in the HV group, with pooled effect size showing a significant large effect (SMD 1.02, 0.48 to 1.57). In contrast, pooled data showed no effects for metatarsus adductus (SMD 0.13, -0.06 to 0.31) and calcaneal inclination angle (SMD 0.00, -0.17 to 0.17). Studies pooled for metatarsus adductus and calcaneal inclination angle were homogenous ($I^2 = 0\%$, $p > 0.10$); however, there was statistically significant heterogeneity across studies that investigated intermetatarsal angle and first metatarsal protrusion distance ($I^2 = 91\%$ and 88%, respectively).

Results from a post hoc sensitivity analysis revealed that pooled effect sizes were not significantly altered after removing one study[8] from the meta-analysis that had used a visual method of HV diagnosis (i.e. the Manchester Scale). Similarly, after removing one juvenile HV study[48] from the meta-analysis, there was no significant change to pooled SMDs for first intermetatarsal angle, metatarsus adductus angle, and calcaneal inclination angle. The pooled SMD for first metatarsal protrusion distance, while noticeably lower (SMD 0.67, CI: 0.38 to 0.96), still denotes a significant moderate effect size, and the reduced heterogeneity (I^2 = 61%, $p > 0.05$) adds strength to this finding.

Effect sizes for individual studies comparing HV and control groups for 39 factors measured on standard radiographic views (dorsoplantar, lateral, and axial sesamoid) are presented in Tables 4, 5 and 6. Thirty-five factors were only investigated by one or two studies; therefore, data pooling was not possible. Dorsoplantar radiographs showed that individuals with a round first metatarsal head were three to five times more likely to have HV (RR 3.14, CI: 2.25 to 4.38[8]; RR 5.42, CI: 3.31 to 8.89[52]). Hallux valgus was also significantly associated with a deviated or subluxed first MTPJ (RR 7.77, 4.07 to 14.85)[8], lateral sesamoid displacement (RR ≥ 5.06)[8], bipartite hallucal sesamoids (RR 2.45, 1.81 to 3.30)[50] and a larger proximal articular set angle (SMD 1.59, 1.35 to 1.83)[8]. Findings from two studies showed that those with HV had a significantly smaller interphalangeal angle (SMD -0.55, -0.76 to -0.33[8]; SMD -1.21, -1.76 to -0.66[44]). On lateral radiographs, those with HV had significantly less first MTPJ dorsiflexion (SMD -1.95, -2.5 to -1.4)[43] and a significantly lower midpoint of the first metatarsocuneiform joint (SMD -0.82, -1.08 to -0.56)[46]. On axial radiographs, sesamoid rotation angle was significantly greater in HV subjects (SMD 2.00, 1.57 to 2.44)[47]. Suzuki *et al.*[53] showed that, in participants with HV, the tibial sesamoid was displaced laterally (SMD 1.41, 0.99 to 1.83), the fibular sesamoid was displaced dorsally (SMD 1.61, 1.18 to 2.04), and the first metatarsal head was displaced in a plantar (SMD -0.60, -0.98 to -0.22) and medial (SMD -1.72, -2.16 to -1.29) direction compared to controls.

Effect sizes for clinical measurements between HV and control groups are reported in Table 7. Seven studies investigating clinical factors (footwear, ankle dorsiflexion, first ray mobility, pronation, arch height, and ligamentous laxity) were excluded from quantitative analysis due to a lack of reported measurement reliability[57-63]. However, five studies investigated clinical factors with adequate reliability. Glasoe *et al.*[54] showed a significant positive association between HV and first ray dorsal mobility (SMD 1.7, 0.83 to 2.57). There were negligible but statistically significant associations between HV and a plantarflexed first metatarsal (RR 1.79, 1.38 to 2.33)[55] and pes planus (RR 1.30, 1.07 to 1.57)[28]. Another study showed no significant difference in arch index between HV and control groups (SMD 0.09, -0.26 to 0.44)[56]. Finally, only one study investigated the association between HV and footwear fit using reliable methods[27], with effect sizes showing that HV participants had inadequately fitting indoor (width: SMD -0.73, -1.08 to -0.38; area: SMD -0.37, -0.72 to -0.03) and outdoor shoes (width: SMD -0.78, -1.12 to -0.44; area: SMD -0.57, -0.91 to -0.23).

Discussion

This is the first study to systematically evaluate and synthesise results from the extensive literature investigating characteristics of foot structure and footwear associated with HV. Data from meta-analyses suggest that greater first intermetatarsal angle and greater first metatarsal protrusion distance, measured on dorsoplantar radiographs, are significantly associated with HV. As statistically significant heterogeneity was found among studies, pooled estimates should be interpreted with caution; however, effects were all in a positive direction. Furthermore, meta-analysis findings were not impacted by the removal of studies using a visual method of HV diagnosis or a juvenile sample. Effect sizes from individual studies highlight a number of other significant radiographic factors relating to the hallux, first metatarsal, first MTPJ and sesamoids, as well as clinical measures of first ray mobility and footwear fit.

The results of this study suggest that a typical presentation of HV would be characterised by an increased first intermetatarsal angle and a long first metatarsal with a round-shaped head. An increased lateral tilt of the first metatarsal articular surface (proximal articular set angle), and a smaller hallux interphalangeal angle would be commonly found on radiographic examination, in addition to various degrees of first MTPJ subluxation and lateral sesamoid displacement, which may be associated with first MTPJ OA[8]. Patients with HV are also more likely to present with bipartite hallucal sesamoid bones, reduced first MTPJ dorsiflexion range, increased mobility at the first metatarsocuneiform joint, and inadequate footwear width; however, few studies have investigated these characteristics with reliable measurement methods[16].

While footwear is often implicated in the development of HV[25, 26], there is currently insufficient evidence to draw this conclusion. Previous reports often cite a study by Sim-Fook and Hodgson[23] which reported that 33% of a shoe-wearing population (n = 118) in Hong Kong had HV, compared to only 2% of a barefoot population (n = 107). While these study findings are interesting, HV was not adequately defined and there was no attempt to adjust for significant differences between groups with regards to age and sex. More recent studies have investigated the association between HV and current and past history of wearing high-heeled shoes[27, 28]. Nguyen *et al.*[28] reported an increased risk of HV in women who had worn high-heeled shoes as their usual shoe type throughout adult life (RR = 1.2, CI: 1.0 to 1.5). In contrast, Menz *et al.*[27] reported no association between HV and past history of wearing high-heeled shoes, but a significant association between HV and current usage of high-heeled outdoor shoes in older women (OR = 2.5, CI: 1.0 to 6.0). Al-Abdulwahab *et al.*[57] investigated the wearing of different shoe types in young females, reporting that 77% of subjects with HV (n = 39) wore shoes with a narrow pointed toe box, while 85% of subjects without HV (n = 61) wore shoes with a wide round toe box. We did not perform further analysis of the above-mentioned study results[27, 28, 57] due to a lack of reported reliability data, which is important due to potential for recall bias when collecting self-report data. The only study included in our analysis that investigated footwear factors with reliable methods showed that HV was associated with insufficient footwear width[27]. Further studies are clearly warranted to investigate the impact of heel height, footwear fitting, and type of footwear in HV.

Another contentious factor highlighted by this review is lowering of the medial longitudinal arch, which has been measured in several ways, including measurements from lateral radiographs (calcaneal inclination angle and navicular height) and clinical observations (arch index, pes planus foot type). Meta-analysis of four studies included in this review[8, 43, 44, 48, 64] revealed no significant difference between HV and control groups in calcaneal inclination angle measurements (SMD = 0.0, CI: -0.17 to 0.17). However, lowering of several lateral radiographic landmarks was found by Komeda et al.[46] (Table 5), most notably lowering of the first metatarsocuneiform joint (SMD = -0.82, -1.08 to -0.56)[46] in those with HV. With regard to radiographic navicular height, one study found a small but statistically significant effect (SMD = -0.40, -0.61 to -0.19)[8], while another study showed no significant difference in navicular height between HV and control groups (SMD = 0.12, -0.39 to 0.62)[44, 64]. Finally, two studies showed a negligible difference between groups for clinical measures of arch index and pes planus[28, 56]. Differences in study findings between radiographic and clinical arch assessments are likely due to the effect of soft tissue on arch index calculations[65]. However, inconsistent findings between studies investigating lateral radiographic measurements may be due to other factors such as differences in study samples and measurement methods.

Other clinical factors that have been discussed in previous HV literature include first ray mobility, generalized ligamentous laxity, and tightness of the gastrocnemius-soleus complex[19, 22, 66]. While Glasoe *et al.*[54] reported a highly significant association between first ray mobility and HV, other studies investigating similar parameters have not demonstrated the reliability of their measurement methods[58, 59], or have not adequately defined HV[67, 68]. Furthermore, studies investigating ligamentous laxity and ankle joint dorsiflexion were excluded from our analysis due to insufficient reliability data[58, 61] or inadequate definition of HV[69, 70]. Each of these clinical factors warrants further investigation using valid and reliable methods.

Several radiographic factors investigated, including metatarsus adductus angle, calcaneal inclination angle, distal articular set angle, metatarsal break angle, metatarsal width, rearfoot-to-forefoot axis angle, talocalcaneal angle, talar declination angle, first metatarsal declination angle and lateral intermetatarsal angle (Tables 4-7), were not significantly different between HV and control groups [8, 44, 46, 54, 64]. Meta-analysis from three studies[8, 44, 48, 64] showed no significant difference in metatarsus adductus angle between HV and control groups, suggesting that any appearance of an adducted first metatarsal in HV is most likely due to an increase in the first intermetatarsal angle rather than an underlying metatarsus adductus.

The findings of this systematic review raise several important concerns regarding study design and methodological quality in the existing HV literature. Some highly cited studies were retrieved by our search strategy but subsequently excluded due to utilising a case-series design, which increases risk of biased conclusions[15, 71]. Furthermore, as studies investigating foot structure and footwear associated with HV have employed cross-sectional rather than prospective study designs, conclusions regarding causality cannot be made. Nevertheless, some factors appear likely to develop as a consequence of HV deformity (e.g. first MTPJ subluxation, lateral sesamoid displacement, or reduced first MTPJ dorsiflexion), while other factors may increase the risk of HV development (e.g. long first metatarsal, round first metatarsal head, pes planus or ill-fitting footwear). Of particular interest to clinicians are those risk factors that may be modifiable through intervention (e.g. footwear fit and heel height), and this review has highlighted that these factors warrant further investigation using rigorous study methodology.

Another issue raised by our quality appraisal was poor reporting of sample characteristics such as age and sex. This is a significant problem as these characteristics are associated with HV prevalence[1] and some risk factors associated with HV have been shown to differ between men and women[28]. Providing an inadequate definition of HV and poor reporting of measurement reliability and validity were widespread problems. Future studies should attempt to utilize prospective designs, although sufficient duration of follow-up may not be feasible in many cases, as HV often has a history of gradual development and progression. Clear reporting of sample characteristics and controlling for confounders such as age and sex in analyses, as well as testing and reporting of measurement reliability and validity, are of utmost importance in undertaking future studies.

This systematic review has demonstrated a strong association between HV and several radiographic observations including: increased first intermetatarsal angle and first metatarsal protrusion distance, round-shaped first metatarsal head, subluxation of the first MTPJ and lateral deviation of the sesamoids. It is therefore important to include these factors in the assessment and monitoring of HV deformity. Furthermore, knowledge of these measures may help guide the selection of appropriate surgical procedures to correct HV deformity. Further research is warranted to investigate other factors that can be readily measured in the clinic using valid and reliable methods, such as joint flexibility and footwear fitting. Prospective studies with long-term follow-up would help to elucidate mechanisms and risk factors for the development of HV. Future studies should consider reporting results according to age and sex, while using appropriate statistical methods to adjust for these potential confounders.

Author contributions

All authors made substantial contributions to the conception and design of the study, interpretation of results, and critical revision of the manuscript. SN conducted database searches, data extraction and analysis. SN and NC rated articles for methodological quality. All authors have approved the final version submitted, and take responsibility for the work as a whole, from inception to finished article (SN: s.nix@qut.edu.au; BV: b.vicenzino@uq.edu.au; NC: n.collins@unimelb.edu.au; MS: m.smith5@uq.edu.au).

Role of the funding source

SN was supported by a Sir Robert Menzies Memorial Scholarship in the Allied Health Sciences, as a doctoral candidate at The University of Queensland, School of Health and

Rehabilitation Sciences. The study sponsors had no involvement in the study design, collection, analysis or interpretation of the data.

Competing interest statement

The authors declare that they have no financial or personal relationships with other people or organisations that may bias this research.

TABLE 1 Selected characteristics of studies included in analysis (16 unique studies)

Study ID/ country	Reference number	Study aim	Study design/ methodology	Definition HV	Selection criteria	Number HV cases (N feet)	Number controls (N feet)	N males/ females	Mean age in years (SD or range)
Bryant 2000; Australia	44, 64	To examine differences in radiographic measurements between HV and control subjects (study also examined subjects with hallux limitus and dynamic plantar pressures, beyond the scope of this review)	Case-control; clinical examination and x-ray	HV angle > 20° (x-ray)	HV group: had symptoms to warrant corrective surgery; excluded if history of previous related foot surgery or inflammatory joint disease; Control group: excluded if clinical or radiological signs of HV, obvious musculoskeletal abnormality of lower limb, foot surgery, significant injury in past 12 months	30 (30 feet)	30 (30 feet)	15/45	45.6 (range: 23 to 74)
D'Arcangelo 2010; Australia	8	To explore relationships between the clinical appearance of HV and x-ray observations in older people	Cross-sectional; x-ray examination	Manchester Scale (none, mild, moderate, severe)	Inclusion criteria: aged 65 years or older, able to walk household distances without the use of a walking aid, and normal cognition; Exclusion criteria: previous HV surgery	NR (258 feet)	NR (144 feet)	74/127	74.9 (SD: 6.6)
Glasoe 2001; USA	54	To compare first ray mobility in HV and control subjects	Case-control; clinical examination and x-ray	HV angle > 20°; intermetatarsal angle > 12° (x-ray)	Exclusion criteria: diabetes, neuromuscular pathology, rheumatoid arthritis or gout, history of forefoot surgery	14	14	4/24	57 (range: 23 to 81)
Kilmartin 1991; UK	55	To investigate the association between first metatarsal position in the sagittal plane and HV	Case-control; clinical examination and x-ray	HV angle > 15° (x-ray)	HV group: clinical evidence of osteophytic lipping of metatarsal head; Control group: no sign of HV in either foot	140 (180 feet)	90 (180 feet)	NR	10
Kilmartin 1992; UK	56	To investigate the relationship between HV and flatfoot in children	Case-control; footprinting and x-ray examination	HV angle > 15° (x-ray)	HV group: 11 year-old children with bilateral deformity and clinical evidence of osteophytic lipping of metatarsal head, no previous treatment; Control group: 11 year-old children with no foot pain or MTPJ deformity	32 (64 feet)	32 (64 feet)	NR	11
Komeda 2001; Japan	46	To investigate radiographic measures of the longitudinal arch in HV and control subjects	Case-control; x-ray examination	HV angle > 20° (x-ray)	HV group: women with symptomatic HV; Control group: female patients treated for minor injury of the contralateral foot or volunteers with no history of foot disease or trauma; Exclusion criteria: rheumatoid arthritis, cerebral palsy, or peripheral nerve disease	110 (186 feet)	72 (93 feet)	0/182	39.7 (range: 13 to 83)
Kuwano 2002; Japan	47	To assess the rotational position of the medial and lateral sesamoids in HV and control subjects	Case-control; x-ray examination	HV angle ≥ 20° (x-ray)	Control group: no forefoot pain or first MTPJ deformity; Exclusion criteria: cerebral infarction, cerebral palsy, peripheral nerve disease, or previous forefoot surgery	29 (58 feet)	32 (64 feet)	7/54	62.5 (range: 16 to 100)
McCluney 2006; Australia	48	To assess radiographic measurements of bone position, length, and angles, in juvenile HV patients compared to controls	Case-control; x-ray examination	HV angle > 15° (x-ray)	Inclusion criteria: children aged 9 to 16 years; Exclusion criteria: non-standard x-rays, inflammatory bone or joint disorders, inherited soft tissue disorders, previous surgical procedures	17	18	15/20	13.5 (SD: 1.8; range: 9 to 16)
Menz 2005; Australia	27	To examine the relationship between footwear characteristics and the prevalence of common forefoot problems in older people	Cross-sectional; clinical examination	Manchester Scale (dichotomised: none/mild = "absent"; moderate-severe = "present")	Inclusion criteria: retirement village residents aged 62 to 96 years; Exclusion criteria: unable to ambulate household distances without an assistive device, cognitive impairment	48	128	56/120	80.1 (SD: 6.4; range: 62 to 96)

TABLE 1 (continued)

Study ID/ country	Reference number	Study aim	Study design/ methodology	Definition HV	Selection criteria	Number HV cases (N feet)	Number controls (N feet)	N males/ females	Mean age in years (SD or range)
Munuera 2006; Spain	49	To determine whether excessive medial deviation of the first metatarsal is present in mild HV cases compared to controls	Case-control; x-ray examination	HV angle > 15° (x-ray)	Inclusion criteria: aged 20 to 29 years; Exclusion criteria: history of foot surgery or trauma, concomitant forefoot deformity, degenerative disease, or neuromuscular imbalance; Control group: first MTPJ range of motion > 65°	33 (49 feet)	43 (49 feet)	20/56	23.1 (SD: 2.6)
Munuera 2007; Spain	50	To examine the incidence of bipartite hallucal sesamoid bones in HV patients compared to controls	Case-control; x-ray examination	HV angle > 15° (x-ray)	Inclusion criteria: aged 20 to 29 years; Exclusion criteria: history of foot surgery or trauma, degenerative disease, or neuromuscular imbalance	NR (119 feet)	NR (355 feet)	139/99	23.8 (SD: 2.7)
Munuera 2008; Spain	51	To examine the length of the first metatarsal and hallux in mild HV cases compared to controls	Case-control; x-ray examination	HV angle > 15° (x-ray)	Inclusion criteria: aged 20 to 29 years; Exclusion criteria: history of foot surgery or trauma, concomitant forefoot deformity, degenerative disease, or neuromuscular imbalance; Control group: first MTPJ range of motion > 65°	27 (54 feet)	49 (98 feet)	30/46	23.3 (SD: 2.6)
Nguyen 2010; USA	28	To examine potential clinical risk factors for HV such as age, BMI, race, education, foot pain, pes planus, and past use of high-heeled shoes in women, in a population-based cohort of community-dwelling older adults	Cross-sectional; clinical examination and interview	HV angle > 15° (visual comparison with photograph)	Inclusion criteria: ability to communicate in English, living within the Boston area, planning to remain in the area over the next 2 yrs, and ability to walk unassisted 20 feet	277	323	214/386	77.9 (SD: 5.6)
Okuda 2007; Japan	52	To retrospectively examine differences in the shape of the lateral edge of the first metatarsal head in women with and without HV	Case-control; x-ray examination	HV angle > 25° or intermetatarsal angle > 12° (x-ray)	Exclusion criteria: previous foot surgery, rheumatoid arthritis or hallux rigidus; HV group: females aged ≥ 21 years with symptomatic HV undergoing corrective surgery; Control group: age-matched females	40 (60 feet)	60 (60 feet)	0/100	51.8 (range: 20 to 83)
Suzuki 2004; Japan	53	To compare measurements of the transverse arch and sesamoid position in HV subjects compared to controls	Case-control; x-ray examination	HV angle ≥ 20° (x-ray)	Exclusion criteria: history of rheumatoid arthritis, cerebral palsy, cerebral infarction, peripheral nerve paralysis, or previous HV surgery; Control group: no foot abnormality noted on visual inspection, no history or treatment of foot disease	34 (59 feet)	29 (51 feet)	18/45	40.8 (range: 12 to 77)
Taranto 2007; Australia	43	To determine the relationship between HV and angle of gait, and several other radiographic angular and linear parameters (study also examined subjects with hallux limitus and dynamic angle of gait parameters, beyond the scope of this review)	Case-control; clinical examination and x-ray	HV angle > 20° (x-ray)	Exclusion criteria: history of lower limb surgery or trauma, neurologic disorders, gait abnormalities, use of walking aids, history of congenital hip dysplasia, systemic disease, or hypermobility syndromes	23 (36 feet)	20 (40 feet)	10/33	60.1 (range: 28 to 82)

HV = hallux valgus, SD = standard deviation, MTPJ = metatarsophalangeal joint

TABLE 2 Summary of studies excluded from further analysis (20 papers; 18 unique studies)

Study ID/ country	Reference number	Study aim	Study design/ methodology	Definition HV	Selection criteria	N HV cases (N feet)	N controls (N feet)	N males/ females	Mean age in years (SD or range)	Associated factors investigated
Al-Abdulwahab 2000; Saudi Arabia	57	To determine severity and distribution of HV and shoes worn in young Saudi Arabian females	Cross-sectional; clinical examination and interview	HV angle > 20° (goniometer)	No current or past foot or ankle pathology	39	61	0/100	22.0 (SD: 9.0)	Shoe type (self-reported)
Eustace 1996; USA	72	To demonstrate a shift in tendon alignment at the first MTPJ in HV patients using magnetic resonance imaging	Case-control; MRI examination	HV angle > 16° and intermetatarsal angle > 9° (coronal plane MRI)	HV group: clinical and radiological evidence of bunions; Control group: no clinical signs of bunion formation	NR (20 feet)	NR (10 feet)	NR	NR	Intermetatarsal angle*, sesamoid position*, first metatarsal pronation*, abductor hallucis tendon position*, flexor hallucis longus tendon position*, extensor hallucis longus tendon position*
Fellner 1995; UK	73	To evaluate the relationship between HV and first metatarsal head shape	Case-control; x-ray examination	HV angle > 15° (x-ray)	HV group: signs of osteophytic thickening around 1st met head; Control group: no indicators of first MTPJ pathology	NR (50 feet)	NR (30 feet)	NR	NR	Metatarsal head curvature
Ferrari 2002; UK	45, 74, 75	To evaluate the relationship of curvature of first metatarsal head and HV	Cross-sectional; x-ray examination	HV angle > 15° (x-ray)	Inclusion criteria: patients in good health aged < 40 years; Exclusion criteria: joint disease affecting first MTPJ (RhA, OA, Charcot); history of first ray surgery or trauma	NR	NR	50/50	29.5 (range: 12-40)	Proximal articular set angle*, metatarsus adductus*, curvature of 1st met head*
Grebing 2004; USA	58	To assess radiographic measurements of second metatarsal length, width, and cortical thickness in relation to mobility of the first ray, pes planus, and tightness of gastroc/soleus in HV and control subjects	Case-control; clinical examination and x-ray	HV angle > 25° (x-ray)	HV group: no concomitant hallux rigidus or neuroma diagnosis; Control group: no symptoms, previous injury or surgery in the included foot (10 were patients having treatment for a corn on the contralateral foot)	43 (43 feet)	43 (43 feet)	10/76	50 (range: 20 to 78)	Ankle dorsiflexion, arch height, first ray mobility, intermetatarsal angle, short first metatarsal, cortical thickness of second metatarsal shaft
Gui 2005; China	59	To investigate the relationship between first ray mobility and HV	Cross-sectional; clinical examination and x-ray	Intermetatarsal angle ≥ 10° and HV angle ≥ 20° (x-ray)	HV group: clinically significant hallux deviation or capsulitis	NR (200 feet)	NR (300 feet)	NR	45 (range: 19 to 78)	First tarsometatarsal joint sagittal mobility, first tarsometatarsal joint deviation*, cortical thickening of second metatarsal shaft*, separation of interosseous space between the tarsus*
Ito 1999; Japan	76	To radiographically examine midtarsal mobility in the sagittal plane in patients with painful HV, painless HV, compared to controls	Case-control; x-ray examination	HV angle > 20° (x-ray)	HV group: female patients only; Control group: volunteers with no foot pain or deformity	NR (54 feet)	NR (23 feet)	NR	47.9 (SD: 20)	Intermetatarsal angle*, metatarsus primus varus*, lateral talar-first metatarsal angle*

TABLE 2 (continued)

Study ID/ country	Reference number	Study aim	Study design/ methodology	Definition HV	Selection criteria	N HV cases (N feet)	N controls (N feet)	N males/ females	Mean age in years (SD or range)	Associated factors investigated
Klein 2009; Austria	60	To investigate the relationship between insufficient length of footwear and HV in children	Cross-sectional; clinical examination	HV angle ≥4° (footprint)	Inclusion criteria: preschool children; Exclusion criteria: foot deformities (clubfoot, pes adductus, visible bunion deformities) or a history of surgical treatment for foot deformities	NR	NR	439/419	4.88 (range: 3 to 6.5)	Indoor shoes fit (length)*, outdoor shoes fit (length)*
LaReaux 1987; USA	77	To examine the relationship between metatarsus adductus and HV	Case-control; x-ray examination	HV angle > 15° (x-ray)	Inclusion criteria: adult patients evidenced by physeal closure on x-ray	NR (230 feet)	NR (230 feet)	(Ratio 1:4)	NR	Metatarsus adductus*
Mancuso 2003; USA	78	To examine the relationship between first metatarsal length and HV	Cross-sectional; x-ray examination	Intermetatarsal angle ≥ 9° (x-ray) and clinical diagnosis of HV	Exclusion criteria: previous first MTPJ surgery	110 (110 feet)	100 (100 feet)	37/173	42.1 (range: 15 to 85)	Intermetatarsal angle*, metatarsal protrusion distance, metatarsal head shape
McNerney 1979; USA	61	To examine the relationship between generalized ligamentous laxity and juvenile HV	Cross-sectional; clinical examination and x-ray	HV angle ≥ 22° and intermetatarsal angle ≥ 11° (x-ray); also clinically observable medial prominence	Exclusion criteria: history of muscular problems, abnormal neurologic signs or medical conditions that might predispose to ligamentous laxity (e.g. rheumatic fever, rheumatoid arthritis, acromegaly)	NR (43 feet)	NR (47 feet)	8/42	NR	Ligamentous laxity*, intermetatarsal angle (1/2, 4/5, 1/5)*, dorsoplantar talocalcaneal angle*, talar declination angle*
Oppel 1984; Germany	63	To examine the prevalence of HV and the influence of sex, weight, height, foot length, and foot type	Case-control; clinical examination and x-ray	HV angle > 10° (x-ray)	School students aged 6 to 18 years	182	219	0/401	(range: 6 to 18)	Foot shape, foot type*, relative foot length*, relative foot width*
Saragas 1995; South Africa	79	To investigate sesamoid position, incidence of pes planus, relative length of the first metatarsal, and the first metatarsal-medial cuneiform joint, in black African females with and without HV	Case-control; x-ray examination	HV angle > 15° (x-ray)	Exclusion criteria: neurologic disorders, inflammatory arthritis, infection, or trauma; Control group: patients attending outpatient department for reasons other than foot problems	NR (52 feet)	NR (66 feet)	0/110	43.0 (range: 20 to 73)	Sesamoid position*, pes planus, first metatarsal length, first metatarsal cuneiform angle
Shimazaki 1981; Japan	80	To examine intermetatarsal angle, sesamoid displacement, and pes planus in HV subjects compared to controls (study also examined electromyography and dynamic plantar pressures, beyond the scope of this review)	Case-control; clinical examination and x-ray	Mild: HV angle 20-35°; severe: HV angle >35° (x-ray)	Exclusion criteria: rheumatoid arthritis, gout or other diseases of the hip and knee joints	28	10	2/36	32 (range: 20 to 65)	Intermetatarsal angle, sesamoid displacement, flat foot/pronated foot

TABLE 2 (continued)

Study ID/ country	Reference number	Study aim	Study design/ methodology	Definition HV	Selection criteria	N HV cases (N feet)	N controls (N feet)	N males/ females	Mean age in years (SD or range)	Associated factors investigated
Stevenson 1990; Australia	62	To investigate the association between pronation and HV	Case-control; clinical examination and questionnaire	HV angle 15-40° (photograph)	HV group: excluded if difficulty ambulating, inflammatory disease, or prior HV corrective surgery; Control group: podiatry patients, excluded if presenting complaint could be related to abnormal foot pronation	62	62	29/95	60.8 (range: 12 to 92)	Pronation/rearfoot eversion*, intermetatarsal angle*, "history of bunions"*
Thordarson 2002; USA	81	To examine hypertrophy of the medial first metatarsal head on x-ray in HV patients compared to controls	Case-control; x-ray examination	HV angle > 15° (x-ray)	HV group: patients undergoing hallux valgus surgery	33 (50 feet)	41 (50 feet)	2/72	NR	Intermetatarsal angle*, medial eminence thickness*
Tokita 1991; Japan	40	To examine intermetatarsal angle and radiographic longitudinal arch measures in HV subjects compared to controls (study also examined dynamic plantar pressure measurements, beyond the scope of this review)	Case-control; clinical examination and x-ray	HV angle > 20° (x-ray)	NR	15 (30 feet)	18 (36 feet)	5/28	33.1 (range: 12 to 60)	Intermetatarsal angle (1/5), medial longitudinal arch height
Vyas 2010; USA	82	To examine radiographic measures of the first metatarsocuneiform joint in juvenile HV patients compared to controls	Case-control; x-ray examination	Intermetatarsal angle > 10° (x-ray)	HV group: symptomatic juvenile HV indicated for corrective surgery, open growth plate physes, no gross concomitant foot deformities; Control group: patients aged 12 to 16 years with no gross foot deformities or other diagnoses involving midfoot or forefoot structure or function	29 (46 feet)	25 (36 feet)	5/49	13.7	Intermetatarsal angle, distal metatarsal articular angle, first metatarsal base-cuneiform angle, first metatarsal-cuneiform angle, second metatarsal-cuneiform angle, cuneiform obliquity, first metatarsal length

HV = hallux valgus, SD = standard deviation, MTPJ = metatarsophalangeal joint
*Insufficient data provided in article to calculate effect size

TABLE 3 Results from quality assessment of all included papers (37 papers)

Study ID	Reference number	Q1. Reported study aim/objective clearly	Q2. Associated factors clearly defined	Q3. HV clearly defined	Q4. Reported study design	Q5. Reported sampling frame	Q6. Reported inclusion criteria	Q7. Reported participation rate	Q8. Reported sample characteristics	Q9. Reported statistical methods	Q10. Reported all basic data	Q11. Reported variability in data	Q12. Reported statistical parameters	Q13. Sample size calculations	Q14. Comparability of case/control groups	Q15. Adequate participation rate	Q16. Recruitment period for case/control groups	Q17. Non-responder characteristics described	Q18. Reliability of all associated factors	Q19. Validity of all associated factors	Q20. Standardised assessment of associated factors	Q21. Blinding of assessors	Q22. Reliability of HV assessment	Q23. Validity of HV assessment	Q24. Standardised assessment of HV	Q25. Assessment period for case/control groups	Q26. Collected data on HV severity/symptoms	Q27. Adjusted for covariates (sex and age)	Q28. Reported data for ≥3 levels of associated factors	Q29. Reported data for subgroups of subjects (e.g. by sex or age)	Q30. Generalizability of results to study population (participation rate)	Q31. Generalizability of results to other populations (random sampling)	Overall quality score (range 0 to 2)
Al-Abdulwahab 2000	57														-		-					-				-							0.78
Bryant 2000*	44																																0.84
Bryant 2000*	64																																0.68
D'Arcangelo 2010	8														-		-					-				-							1.04
Eustace 1996	72														-		-					-				-							0.22
Fellner 1995	73																																0.52
Ferrari 2002*	74														-		-					-				-							0.96
Ferrari 2002*	45														-		-					-				-							1.04
Ferrari 2002*	75														-		-					-				-							0.96
Glasoe 2001	54																																0.71
Grebing 2004	58																	-													-		1.03
Gui 2005	59														-		-									-							0.54
Ito 1999	76																																0.71
Kilmartin 1991	55																																0.48
Kilmartin 1992	56																																0.65
Klein 2009	60														-		-					-				-							1.52
Komeda 2001	46																																0.71
Kuwano 2002	47																																0.81
LaReaux 1987	77																																0.55
Mancuso 2003	78														-		-					-				-							0.89
McCluney 2006	48																																1.19
McNerney 1979	61														-		-					-											0.74
Menz 2005	27														-		-					-				-							0.96
Munuera 2006	49																																1.13
Munuera 2007	50														-		-					-				-							1.19
Munuera 2008	51																-																1.03
Nguyen 2010	28														-		-					-				-							1.44
Okuda 2007	52																																0.90
Oppel 1984	63																																0.26
Saragas 1995	79																																0.68
Shimazaki 1981	80																																0.39
Stevenson 1990	62																	-													-		0.97
Suzuki 2004	53																																0.68
Taranto 2007	43																																1.19
Thordarson 2002	81																																0.52
Tokita 1991	40																																0.26
Vyas 2010	82																																0.74
Studies scoring "Yes" (%)		78	68	57	14	22	65	11	73	14	65	49	30	0	25	5	4	9	27	35	35	0	38	68	22	4	0	16	22	24	3	3	

HV = hallux valgus, Black shading = "Yes", Grey shading = "Partial", White (no shading) = "No" or "Unable to determine", "-" = "Not applicable", items removed from scoring and not included in % calculations
* More than one paper reporting results from the same study; papers were quality rated separately but given the same study ID for the purpose of further analysis

TABLE 4 Comparison of dorsoplantar radiographic observations between HV and control subjects

Angular and length measurements	Study ID	Reference number	N HV cases	N controls	SMD	95% CI
First intermetatarsal angle*	Bryant 2000	44, 64	30	30	1.43	0.86 to 2.0
	D'Arcangelo 2010	8	124	278	1.24	1.01 to 1.47
	McCluney 2006	48	17	18	1.16	0.44 to 1.88
	Munuera 2006	49	49	49	0.56	0.16 to 0.96
	Okuda 2007	52	60	60	3.07	2.54 to 3.6
	Taranto 2007	43	36	40	1.51	1.00 to 2.02
Metatarsus adductus angle	Bryant 2000	44, 64	30	30	0.40	-0.11 to 0.91
	D'Arcangelo 2010	8	124	278	0.08	-0.13 to 0.30
	McCluney 2006	48	17	18	0.09	-0.57 to 0.75
Simplified metatarsus adductus angle	D'Arcangelo 2010	8	124	278	0.24	0.03 to 0.46
Hallux interphalangeal angle	Bryant 2000	44, 64	30	30	-1.21	-1.76 to -0.66
	D'Arcangelo 2010	8	124	278	-0.55	-0.76 to -0.33
Proximal articular set angle	D'Arcangelo 2010	8	124	278	1.59	1.35 to 1.83
Distal articular set angle	D'Arcangelo 2010	8	124	278	-0.16	-0.37 to 0.05
Metatarsal break angle	Bryant 2000	44, 64	30	30	0.47	-0.05 to 0.98
Metatarsal width	Bryant 2000	44, 64	30	30	0.48	-0.03 to 1.0
Rearfoot-to-forefoot axis angle	Taranto 2007	43	36	40	-0.16	-0.61 to 0.29
First metatarsal length	Munuera 2008	51	54	98	0.69	0.35 to 1.03
Hallux length	Munuera 2008	51	54	98	0.60	0.26 to 0.94
First metatarsal protrusion distance	Bryant 2000	44, 64	30	30	1.02	0.48 to 1.56
	D'Arcangelo 2010	8	124	278	0.67	0.46 to 0.89
	McCluney 2006	48	17	18	3.45	2.39 to 4.52
	Munuera 2008	51	54	98	0.84	0.50 to 1.19
	Taranto 2007	43	36	40	0.15	-0.30 to 0.60
Other observations (dichotomised)					**RR**	**95% CI**
Round first metatarsal head	D'Arcangelo 2010	8	124	278	3.14	2.25 to 4.38
	Okuda 2007	52	60	60	5.42	3.31 to 8.89
Deviated or subluxed first MTPJ	D'Arcangelo 2010	8	124	278	7.77	4.07 to 14.85
Sesamoid lateral displacement						
Four grade scale (dichotomised)	D'Arcangelo 2010	8	124	278	5.06	3.74 to 6.83
Seven position scale (dichotomised)	D'Arcangelo 2010	8	124	278	5.53	4.01 to 7.61
Bipartite sesamoid	Munuera 2007	50	119	355	2.45	1.81 to 3.30

HV = hallux valgus, SMD = standardized mean difference, CI = confidence interval, RR = risk ratio

*Note: Some studies use the term “metatarsus primus varus” instead of “first intermetatarsal angle”; however, the measurement method is the same.

TABLE 5 Comparison of lateral radiographic observations between HV and control subjects

Angular measurements and structural coordinates	Study ID	Reference number	N HV cases	N controls	SMD	95% CI
Calcaneal inclination angle	Bryant 2000	44, 64	30	30	0.04	-0.47 to 0.54
	D'Arcangelo 2010	8	124	278	0.03	-0.19 to 0.24
	McCluney 2006	48	17	18	0.24	-0.43 to 0.91
	Taranto 2007	43	36	40	-0.26	-0.71 to 0.20
Talocalcaneal angle	Bryant 2000	44, 64	30	30	0.09	-0.42 to 0.59
Talar declination angle	Bryant 2000	44, 64	30	30	-0.05	-0.56 to 0.46
First metatarsal declination angle	Bryant 2000	44, 64	30	30	0.36	-0.16 to 0.87
	D'Arcangelo 2010	8	124	278	-0.12	-0.33 to 0.10
Fifth metatarsal declination angle	Bryant 2000	44, 64	30	30	0.16	-0.35 to 0.66
Lateral intermetatarsal angle	D'Arcangelo 2010	8	124	278	-0.06	-0.27 to 0.15
	Taranto 2007	43	36	40	-0.06	-0.51 to 0.39
Lateral stressed dorsiflexion of first MTPJ	Taranto 2007	43	36	40	-1.95	-2.5 to -1.4
Navicular height	Bryant 2000	44, 64	30	30	0.12	-0.39 to 0.62
Navicular height/truncated foot length	D'Arcangelo 2010	8	124	278	-0.40	-0.61 to -0.19
Lowest point of the anterior joint surface of the calcaneus (x)	Komeda 2001	46	186	93	-0.15	-0.40 to 0.10
(y)	Komeda 2001	46	186	93	-0.60	-0.85 to -0.34
Lowest point of the cuboid (x)	Komeda 2001	46	186	93	0.00	-0.25 to 0.25
(y)	Komeda 2001	46	186	93	-0.41	-0.66 to -0.16
Midpoint of the first cuneiform-navicular joint (x)	Komeda 2001	46	186	93	0.56	0.31 to 0.81
(y)	Komeda 2001	46	186	93	-0.68	-0.93 to -0.42
Midpoint of the first metatarsocuneiform joint (x)	Komeda 2001	46	186	93	0.66	0.40 to 0.91
(y)	Komeda 2001	46	186	93	-0.82	-1.08 to -0.56
Midpoint of the talonavicular joint (x)	Komeda 2001	46	186	93	0.50	0.25 to 0.75
(y)	Komeda 2001	46	186	93	-0.64	-0.90 to -0.39
Midpoint of the tibiotalar joint (x)	Komeda 2001	46	186	93	0.52	0.27 to 0.78
(y)	Komeda 2001	46	186	93	-0.53	-0.79 to -0.28

HV = hallux valgus, SMD = standardized mean difference, CI = confidence interval

TABLE 6 Comparison of axial radiographic observations between HV and control subjects

Angular measurements and structural coordinates	Study ID	Reference number	N HV cases	N controls	SMD	95% CI
Sesamoid rotation angle	Kuwano 2002	47	58	64	2.00	1.57 to 2.44
Position of first metatarsal head (x)	Suzuki 2004	53	59	51	-1.72	-2.16 to -1.29
(y)	Suzuki 2004	53	59	51	-0.60	-0.98 to -0.22
Position of second metatarsal head (x)	Suzuki 2004	53	59	51	0.00	-
(y)	Suzuki 2004	53	59	51	-0.69	-1.07 to -0.30
Position of third metatarsal head (x)	Suzuki 2004	53	59	51	0.44	0.06 to 0.82
(y)	Suzuki 2004	53	59	51	-0.50	-0.88 to -0.12
Position of fourth metatarsal head (x)	Suzuki 2004	53	59	51	0.16	-0.22 to 0.53
(y)	Suzuki 2004	53	59	51	-0.09	-0.46 to 0.29
Position of fifth metatarsal head (x)	Suzuki 2004	53	59	51	0.11	-0.27 to 0.48
(y)	Suzuki 2004	53	59	51	0.22	-0.15 to 0.60
Position of tibial sesamoid (x)	Suzuki 2004	53	59	51	1.41	0.99 to 1.83
(y)	Suzuki 2004	53	59	51	0.14	-0.23 to 0.52
Position of fibular sesamoid (x)	Suzuki 2004	53	59	51	0.65	0.26 to 1.03
(y)	Suzuki 2004	53	59	51	1.61	1.18 to 2.04

HV = hallux valgus, SMD = standardized mean difference, CI = confidence interval

TABLE 7 Comparison of clinical observations between HV and control subjects

Clinical measurement	Study ID	Reference number	N HV cases	N controls	Effect size (SMD, unless otherwise stated)	95% CI
First ray dorsal mobility	Glasoe 2001	54	14	14	1.70	0.83 to 2.57
Plantarflexed first metatarsal (present/absent) (RR)	Kilmartin 1991	55	180	180	1.79	1.38 to 2.33
Arch index	Kilmartin 1992	56	64	64	0.09	-0.26 to 0.44
Pes planus (present/absent) (RR)	Nguyen 2010	28	277	323	1.30	1.07 to 1.57
Indoor shoe fit:						
length*	Menz 2005	27	44	123	-0.18	-0.52 to 0.17
width*	Menz 2005	27	44	123	-0.73	-1.08 to -0.38
area*	Menz 2005	27	44	123	-0.37	-0.72 to -0.03
Outdoor shoe fit:						
length*	Menz 2005	27	48	128	-0.29	-0.62 to 0.05
width*	Menz 2005	27	48	128	-0.78	-1.12 to -0.44
area*	Menz 2005	27	48	128	-0.57	-0.91 to -0.23

HV = hallux valgus, SMD = standardized mean difference, CI = confidence interval, RR = risk ratio
* % difference compared to foot

Figures

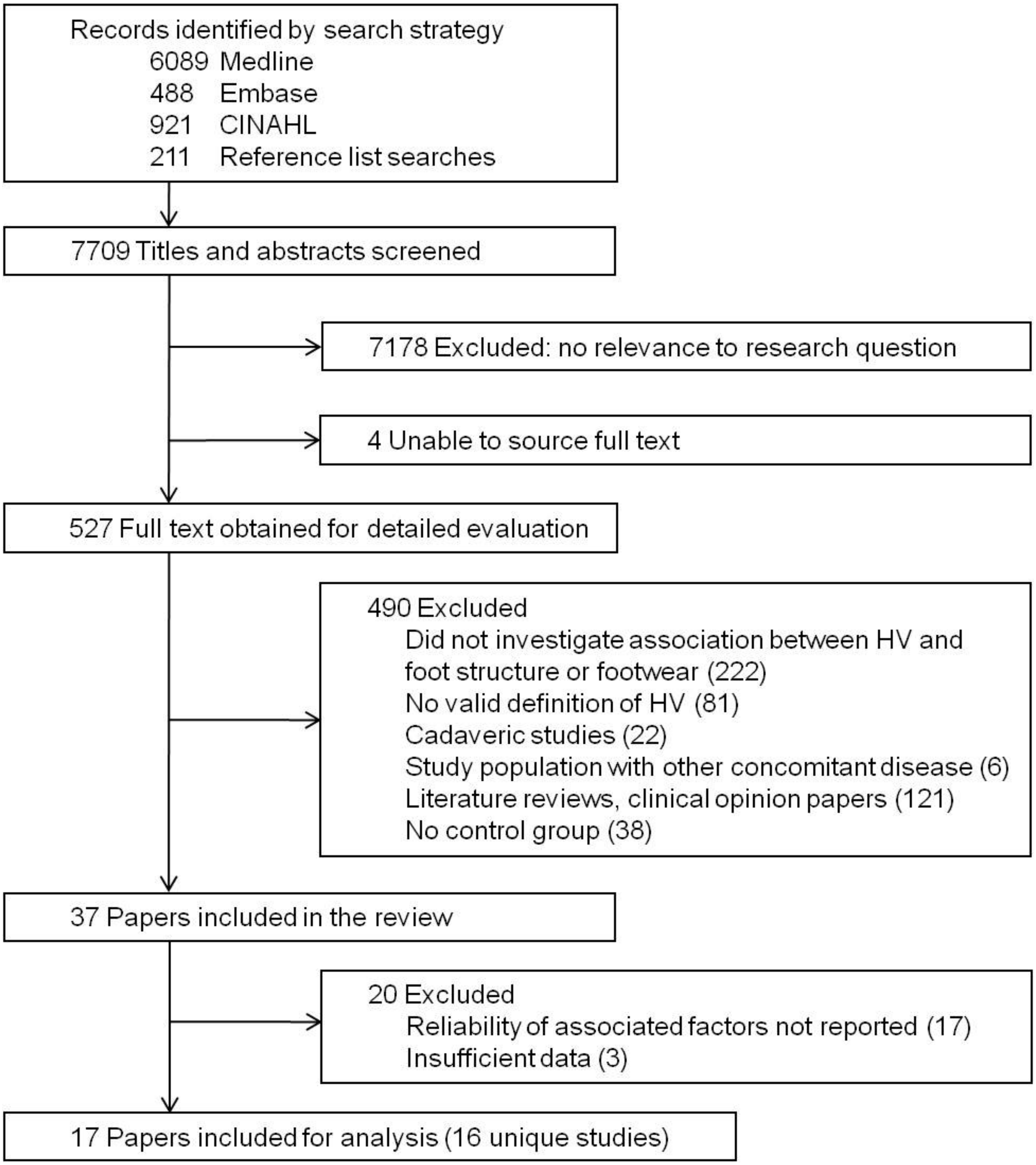

Figure 1 Flowchart of study selection procedure

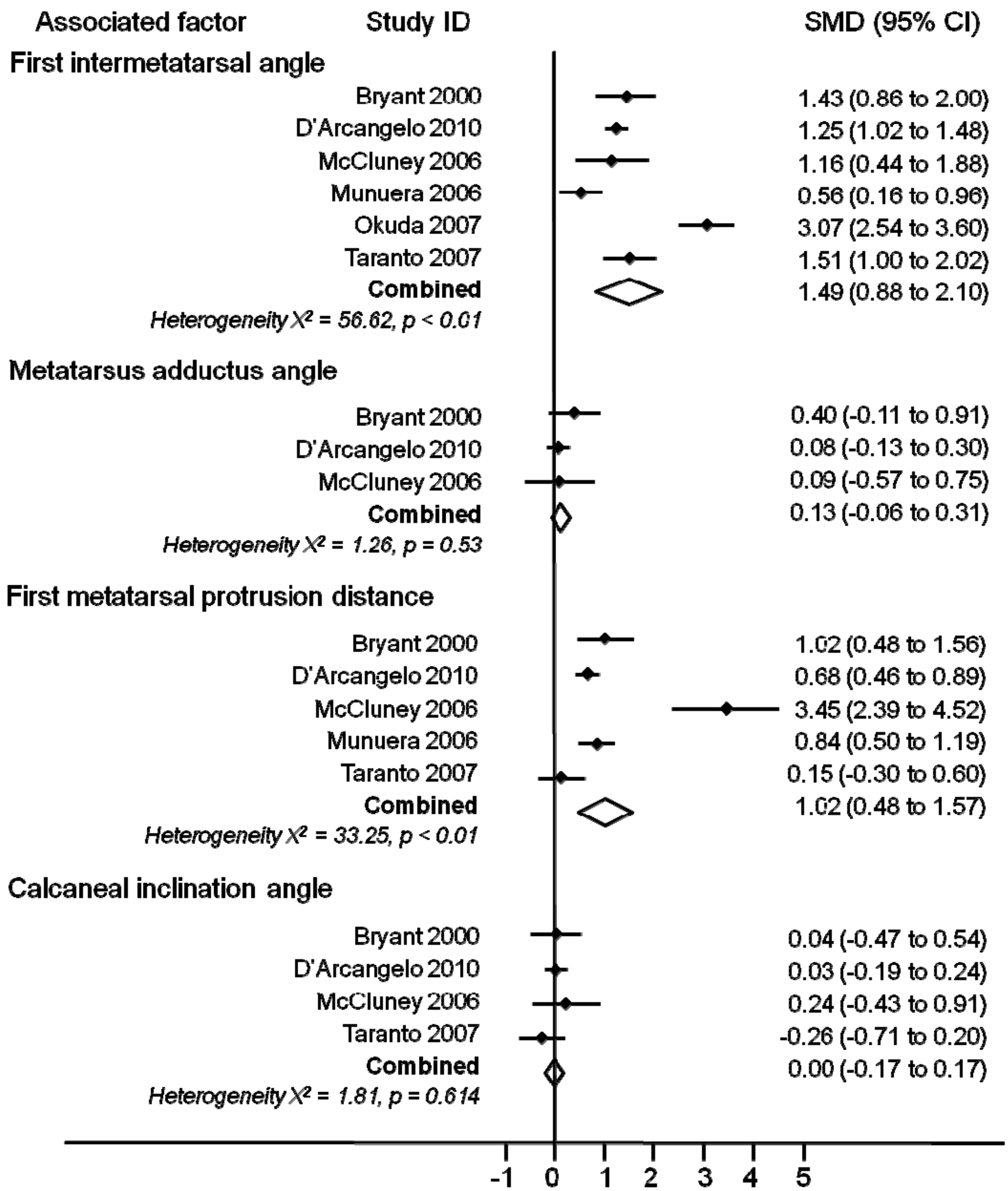

Figure 2 Pooled effect sizes for intermetatarsal angle, metatarsus adductus angle, first metatarsal protrusion distance, and calcaneal inclination angle

References

1. Nix S, Smith M, Vicenzino B. Prevalence of hallux valgus in the general population: a systematic review and meta-analysis. J Foot Ankle Res. 2010;3(1):21.

2. Meyr AJ, Adams ML, Sheridan MJ, Ahalt RG. Epidemiological Aspects of the Surgical Correction of Structural Forefoot Pathology. J Foot Ankle Surg. 2009;48(5):543-551.

3. Abhishek A, Roddy E, Zhang W, Doherty M. Are hallux valgus and big toe pain associated with impaired quality of life? A cross-sectional study. Osteoarthritis Cartilage. 2010;18(7):923-926.

4. Cho NH, Kim S, Kwon DJ, Kim HA. The prevalence of hallux valgus and its association with foot pain and function in a rural Korean community. J Bone Joint Surg Br. 2009;91(4):494-498.

5. Menz HB, Morris ME. Determinants of disabling foot pain in retirement village residents. J Am Podiatr Med Assoc. 2005;95(6):573-579.

6. Menz HB, Roddy E, Thomas E, Croft PR. Impact of hallux valgus severity on general and foot-specific health-related quality of life. Arthritis Care Res (Hoboken). 2011;63(3):396-404.

7. Roddy E, Zhang W, Doherty M. Prevalence and associations of hallux valgus in a primary care population. Arthritis Rheum. 2008;59(6):857-862.

8. D'Arcangelo P, Landorf K, Munteanu S, Zammit G, Menz H. Radiographic correlates of hallux valgus severity in older people. J Foot Ankle Res. 2010;3(1):20.

9. Menz HB, Lord SR. Gait instability in older people with hallux valgus. Foot Ankle Int. 2005;26(6):483-489.

10. Koski K, Luukinen H, Laippala P, Kivela SL. Physiological factors and medications as predictors of injurious falls by elderly people: a prospective population-based study. Age Ageing. 1996;25(1):29-38.

11. Menz HB, Morris ME, Lord SR. Foot and ankle risk factors for falls in older people: a prospective study. The Journals of Gerontology Series A, Biological Sciences and Medical Sciences. 2006;61(8):866-870.

12. Mickle KJ, Munro BJ, Lord SR, Menz HB, Steele JR. ISB Clinical Biomechanics Award 2009. Toe weakness and deformity increase the risk of falls in older people. Clin Biomech (Bristol, Avon). 2009;24(10):787-791.

13. Spink MJ, Fotoohabadi MR, Wee E, Hill KD, Lord SR, Menz HB. Foot and ankle strength, range of motion, posture, and deformity are associated with balance and functional ability in older adults. Arch Phys Med Rehabil. 2011;92(1):68-75.

14. Hardy RH, Clapham JCR. Observations on hallux valgus; based on a controlled series. J Bone Joint Surg Br. 1951;33(3):376-391.

15. Piggott H. The natural history of hallux valgus in adolescence and early adult life. J Bone Joint Surg Br. 1960;42(4):749-760.

16. Coughlin MJ, Jones CP. Hallux valgus: demographics, etiology, and radiographic assessment. Foot Ankle Int. 2007;28(7):759-777.

17. Coughlin MJ. Hallux valgus. J Bone Joint Surg Am. 1996;78(6):932-966.

18. Vanore JV, Christensen JC, Kravitz SR, Schuberth JM, Thomas JL, Weil LS, et al. Diagnosis and treatment of First Metatarsophalangeal Joint Disorders. Section 1: Hallux valgus. J Foot Ankle Surg. 2003;42(3):112-123.

19. Robinson AHN, Limbers JP. Modern concepts in the treatment of hallux valgus. J Bone Joint Surg Br. 2005;87(8):1038-1045.

20. Srivastava S, Chockalingam N, El Fakhri T. Radiographic measurements of hallux angles: A review of current techniques. Foot. 2010;20(1):27-31.

21. Kilmartin TE, Wallace WA. The aetiology of hallux valgus: A critical review of the literature. Foot. 1993;3(4):157-167.

22. Harris MR, Beeson P. Is there a link between juvenile hallux abducto valgus and generalized hypermobility? A review of the literature. Part I. Foot. 1998;8(3):125-128.
23. Sim-Fook LAM, Hodgson AR. A Comparison of Foot Forms Among the Non-Shoe and Shoe-Wearing Chinese Population. J Bone Joint Surg Am. 1958;40(5):1058-1062.
24. Kato T, Watanabe S. The etiology of hallux valgus in Japan. Clin Orthop Relat Res. 1981;No.157:78-81.
25. Coughlin MJ, Thompson FM. The high price of high-fashion footwear. Instr Course Lect. 1995;44:371-377.
26. Frey C. Foot health and shoewear for women. Clin Orthop Relat Res. 2000;372:32-44.
27. Menz HB, Morris ME. Footwear characteristics and foot problems in older people. Gerontology. 2005;51(5):346-351.
28. Nguyen USDT, Hillstrom HJ, Li W, Dufour AB, Kiel DP, Procter-Gray E, et al. Factors associated with hallux valgus in a population-based study of older women and men: the MOBILIZE Boston Study. Osteoarthritis Cartilage. 2010;18(1):41-46.
29. Cush GJ, Marks RM. Hallux valgus and common problems of the first ray. Curr Opin Orthop. 2005;16(2):72-76.
30. Deschamps K, Birch I, Desloovere K, Matricali GA. The impact of hallux valgus on foot kinematics: A cross-sectional, comparative study. Gait Posture. 2010;32(1):102-106.
31. Yavuz M, Hetherington VJ, Botek G, Hirschman GB, Bardsley L, Davis BL. Forefoot plantar shear stress distribution in hallux valgus patients. Gait Posture. 2009;30(2):257-259.
32. Genaidy AM, Lemasters GK, Lockey J, Succop P, Deddens J, Sobeih T, et al. An epidemiological appraisal instrument - a tool for evaluation of epidemiological studies. Ergonomics. 2007;50(6):920-960.
33. Garrow AP, Papageorgiou A, Silman AJ, Thomas E, Jayson MI, Macfarlane GJ. The grading of hallux valgus. The Manchester Scale. J Am Podiatr Med Assoc. 2001;91(2):74-78.
34. Menz HB, Fotoohabadi M, Wee E, Spink M. Validity of self-assessment of hallux valgus using the Manchester scale. BMC Musculoskelet Disord. 2010;11(1):215.
35. Stata Statistical Software: Release 10 [computer program]. College Station, TX: StataCorp LP; 2007.
36. Deeks JJ, Higgins JPT, Altman DG. Analysing data and undertaking meta-analyses. In: Higgins JPT, Green S, eds. Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0 [updated March 2011] ed: The Cochrane Collaboration; 2011.
37. Cohen J. A power primer. Psychol Bull. 1992;112(1):155.
38. Citrome L. Relative vs. absolute measures of benefit and risk: what's the difference? Acta Psychiatr Scand. 2010;121(2):94-102.
39. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. Br Med J. 2003;327(7414):557-560.
40. Tokita F, Obara N, Miyano S, Kura H, Sasaki T, Kobayashi H. A study on the distribution of foot sole pressure of hallux valgus. Hokkaido J Orthop Traum Surg. 1991;35(2):33-37.
41. Duke H, Newman LM, Bruskoff BL, Daniels R. Relative metatarsal length patterns in hallux abducto valgus. J Am Podiatr Med Assoc. 1982;72(1):1-5.
42. Greenberg GS. Relationship of hallux abductus angle and first metatarsal angle to severity of pronation. J Am Podiatry Assoc. 1979;69(1):29-34.
43. Taranto J, Taranto MJ, Bryant AR, Singer KP. Analysis of dynamic angle of gait and radiographic features in subjects with hallux abducto valgus and hallux limitus. J Am Podiatr Med Assoc. 2007;97(3):175-188.
44. Bryant A, Tinley P, Singer K. A comparison of radiographic measurements in normal, hallux valgus, and hallux limitus feet. J Foot Ankle Surg. 2000;39(1):39-43.
45. Ferrari J, Malone-Lee J. Relationship between proximal articular set angle and hallux abducto valgus. J Am Podiatr Med Assoc. 2002;92(6):331-335.

46. Komeda T, Tanaka Y, Takakura Y, Fujii T, Samoto N, Tamai S. Evaluation of the longitudinal arch of the foot with hallux valgus using a newly developed two-dimensional coordinate system. J Orthop Sci. 2001;6(2):110-118.
47. Kuwano T, Nagamine R, Sakaki K, Urabe K, Iwamoto Y. New radiographic analysis of sesamoid rotation in hallux valgus: comparison with conventional evaluation methods. Foot Ankle Int. 2002;23(9):811-817.
48. McCluney JG, Tinley P. Radiographic measurements of patients with juvenile hallux valgus compared with age-matched controls: a cohort investigation. J Foot Ankle Surg. 2006;45(3):161-167.
49. Munuera PV, Dominguez G, Polo J, Rebollo J. Medial deviation of the first metatarsal in incipient hallux valgus deformity. Foot Ankle Int. 2006;27(12):1030-1035.
50. Munuera PV, Dominguez G, Reina M, Trujillo P. Bipartite hallucal sesamoid bones: relationship with hallux valgus and metatarsal index. Skeletal Radiol. 2007;36(11):1043-1050.
51. Munuera PV, Polo J, Rebollo J. Length of the first metatarsal and hallux in hallux valgus in the initial stage. Int Orthop. 2008;32(4):489-495.
52. Okuda R, Kinoshita M, Yasuda T, Jotoku T, Kitano N, Shima H. The shape of the lateral edge of the first metatarsal head as a risk factor for recurrence of hallux valgus. J Bone Joint Surg Am. 2007;89(10):2163-2172.
53. Suzuki J, Tanaka Y, Takaoka T, Kadono K, Takakura Y. Axial radiographic evaluation in hallux valgus: evaluation of the transverse arch in the forefoot. J Orthop Sci. 2004;9(5):446-451.
54. Glasoe WM, Allen MK, Saltzman CL. First ray dorsal mobility in relation to hallux valgus deformity and first intermetatarsal angle. Foot Ankle Int. 2001;22(2):98-101.
55. Kilmartin TE, Wallace A, Hill TW. First metatarsal position in juvenile hallux abducto-valgus a significant clinical measurement. J Br Podiatr Med. 1991;3:43-45.
56. Kilmartin TE, Wallace WA. The significance of pes planus in juvenile hallux valgus. Foot Ankle. 1992;13(2):53-56.
57. Al-Abdulwahab SS, Al-Dosry RD. Hallux valgus and preferred shoe types among young healthy Saudi Arabian females. Ann Saudi Med. 2000;20(3-4):319-321.
58. Grebing BR, Coughlin MJ. Evaluation of Morton's theory of second metatarsal hypertrophy. J Bone Joint Surg Am. 2004;86(7):1375-1386.
59. Gui J-C, Gu X-J, Wang L-M, Shen H-Q, Yu Z, Ma X, et al. [Sagittal mobility study on the first tarsometatarsal joint in hallux valgus patients and its clinical values]. Chung Hua Wai Ko Tsa Chih. 2005;43(4):259-262.
60. Klein C, Groll-Knapp E, Kundi M, Kinz W. Increased hallux angle in children and its association with insufficient length of footwear: a community based cross-sectional study. BMC Musculoskelet Disord. 2009;10:159.
61. McNerney JE, Johnston WB. Generalized ligamentous laxity, hallux abducto valgus and the first metatarsocuneiform joint. J Am Podiatry Assoc. 1979;69(1):69-82.
62. Stevenson M. A study of the correlation between neutral calcaneal stance position and relaxed calcaneal stance position in the development of hallux abducto valgus. Aust Podiatrist. 1990;24:18-20.
63. Oppel U, Bajer D, Wilke U. Epidemiology and early functional treatment of the hallux valgus in juveniles. Orthopadische Praxis. 1984;20(7):533-537.
64. Bryant A, Tinley P, Singer K. Radiographic measurements and plantar pressure distribution in normal, hallux valgus and hallux limitus feet. Foot. 2000;10(1):18-22.
65. Wearing SC, Hills AP, Byrne NM, Hennig EM, McDonald M. The arch index: a measure of flat or fat feet? Foot Ankle Int. 2004;25(8):575-581.
66. Myerson MS, Badekas A. Hypermobility of the first ray. Foot Ankle Clin. 2000;5(3):469-484.

67. Klaue K, Hansen ST, Masquelet AC. Clinical, quantitative assessment of first tarsometatarsal mobility in the sagittal plane and its relation to hallux valgus deformity. Foot Ankle Int. 1994;15(1):9-13.
68. Lee KT, Young K. Measurement of first-ray mobility in normal vs. hallux valgus patients. Foot Ankle Int. 2001;22(12):960-964.
69. Harris MCR, Beeson P. Generalized hypermobility: Is it a predisposing factor towards the development of juvenile hallux abducto valgus? Part 2. Foot. 1998;8(4):203-209.
70. Carl A, Ross S, Evanski P, Waugh T. Hypermobility in hallux valgus. Foot Ankle. 1988;8(5):264-270.
71. Bonney G, Macnab I. Hallux valgus and hallux rigidus; a critical survey of operative results. J Bone Joint Surg Br. 1952;34(3):366-385.
72. Eustace S, Williamson D, Wilson M, O'Byrne J, Bussolari L, Thomas M, et al. Tendon shift in hallux valgus: observations at MR imaging. Skeletal Radiology. 1996;25(6):519-524.
73. Fellner D, Milsom PB. Relationship between hallux valgus and first metatarsal head shape. J Br Podiatr Med. 1995;50(4):54-56.
74. Ferrari J, Malone-Lee J. The shape of the metatarsal head as a cause of hallux abductovalgus. Foot Ankle Int. 2002;23(3):236-242.
75. Ferrari J, Malone-Lee J. A radiographic study of the relationship between metatarsus adductus and hallux valgus. J Foot Ankle Surg. 2003;42(1):9-14.
76. Ito H, Shimizu A, Miyamoto T, Katsura Y, Tanaka K. Clinical significance of increased mobility in the sagittal plane in patients with hallux valgus. Foot Ankle Int. 1999;20(1):29-32.
77. La Reaux RL, Lee BR. Metatarsus adductus and hallux abducto valgus: their correlation. J Foot Surg. 1987;26(4):304-308.
78. Mancuso JE, Abramow SP, Landsman MJ, Waldman M, Carioscia M. The zero-plus first metatarsal and its relationship to bunion deformity. J Foot Ankle Surg. 2003;42(6):319-326.
79. Saragas NP, Becker PJ. Comparative radiographic analysis of parameters in feet with and without hallux valgus. Foot Ankle Int. 1995;16(3):139-143.
80. Shimazaki K, Takebe K. Investigations on the origin of hallux valgus by electromyographic analysis. Kobe J Med Sci. Aug 1981;27(4):139-158.
81. Thordarson DB, Krewer P. Medial eminence thickness with and without hallux valgus. Foot Ankle Int. 2002;23(1):48-50.
82. Vyas S, Conduah A, Vyas N, Otsuka NY. The role of the first metarsocuneiform joint in juvenile hallux valgus. J Pediatr Orthop B. Sep 2010;19(5):399-402.