Gait and Posture 15 (2002) 282–291
www.elsevier.com/locate/gaitpost

Review

Foot type classification: a critical review of current methods

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Received 14 September 2000; received in revised form 24 May 2001; accepted 8 June 2001

Abstract

Investigation into the effects of foot structure on foot function, and the risks of injury, has been at the core of many studies, sometimes with conflicting results. Often different methods of foot type classification have been used, making comparison of the results and drawing sound conclusions impossible. This article aims to critically review current methods of foot type classification. It is concluded that if a classification method combines data on structure with information on foot function in dynamic loading situations, it should relate more closely to the functional behaviour of the foot during locomotion.

Keywords: Locomotion; Gait; Running; Foot type classification; Foot function; Foot structure; Kinematics; Risk of injury

1. Introduction

It is generally believed that the function of the foot depends, to a significant extent, on the shape of the foot. Despite having many common anatomical characteristics, the shape and biomechanics of the foot differ greatly between individuals. Much of the clinical research has focused on the medial longitudinal arch (MLA) as a source of variability. Many different factors are considered to be influential on the formation and function of the MLA. Age [1], gender [2], race [3], shoes [4], and age at which wearing shoes begins [5] are among factors noted to influence the formation of the arch.

The significance of the shape of the MLA has been one of the most controversial issues in many foot-related sciences. Both high and low arched feet have been reported to be factors making the foot more prone to injury during physical activities [6].

To evaluate any proposed relationship between foot structure and foot function, and between foot shape and risk of injury, it is essential to apply a valid and reliable system of foot type classification. The purpose of this article is to critically review different methods of foot type classification. A description of some commonly used methods will be presented, with a critique of advantages and disadvantages of these methods.

2. Methods of classification

In a review of the literature, it is clear that no general consensus exists on an ideal method for foot type classification. Existing methods are typically based on the measurement of morphological parameters of the foot, mostly in the standing weight-bearing position, or during locomotion. A minority employ foot functional characteristics to assign different feet into separate groups. Methods of foot type classification based on foot morphology could be put into one of the following categories:

- Visual non-quantitative inspection.
- Anthropometric values.
- Footprint parameters.
- Radiographic evaluation.

A brief description will be given of each method, followed by a section reviewing measurement techniques that have used criteria of foot function.

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0966-6362/02/$ - see front matter
PII: S0966-6362(01)00151-5

2.1. Visual non-quantitative inspection

As a part of the routine clinical examination of any foot problem, inspection can be made from front, sides and back of the foot in the non-weight-bearing and weight-bearing positions and during walking to observe presence or absence of foot curvatures. Such evaluation may utilise photographs or videos taken in different views to facilitate evaluation by the examiner or provide documentation for future assessment and comparison. A podoscope provides more detailed evaluation by employing a mirror to show the contact area beneath the foot.

Visual assessment is a simple method of evaluating the curvature and alignment of the foot, readily available to clinicians. By employing a visual appraisal method, Dahle et al. [7] reported a 73.3% agreement in the assignment of the evaluated feet into three groups of pronated, supinated, and neutral among three experienced physical therapists. The classification was based on qualitative estimates of arch angle and rearfoot alignment, and presence or absence of a talonavicular bulge. No separate reliability Interclass Correlation Coefficient (ICC) was reported for the three variables used in the study. However, any attempt to characterise the foot in this way is subjective and provides limited information—the ICC and the level of agreement between different examiners for the visual non-quantitative assessment of the MLA on plane photographs of the subjects' feet has been found to be poor [8]. Foot type classification based on the direct observation of medial, posterior, anterior, and plantar aspects of the foot has also been reported to demonstrate significantly high variability [9]. To quantify such evaluation, markers may be placed upon bony prominences or soft tissues to identify and measure the desired foot characteristics more easily and accurately. Some of such modifications will be reviewed in the next section.

2.2. Anthropometric values

Anthropometric (clinical) approaches to characterise the foot involve direct measurement of surface landmarks or bony eminences representing the location and position of different structures within the foot, including the MLA. The examiner is provided with information on the sagittal or frontal plane orientation of foot segments, which can be used to classify foot type. Recognised anthropometric values are as follows.

2.2.1. Arch height

Direct measurement of the highest point of the MLA in the sagittal plane is one of the simplest methods of providing the clinician with quantifiable information regarding foot structure. The prominent navicular bone generally represents the highest point of the MLA and a ruler may be used to measure the distance between this point and the supporting surface. Alternatively, the highest point along the soft tissue margin of the medial plantar curvature may be used as the reference point. Use of callipers may improve the accuracy of direct measurement of the arch height. Hawes et al. [9] reported high intratester (0.99) and intertester (0.98) reliability for direct arch height measurement by a modified Mitutoyo digital calliper.

The reliability of several anthropometric measurements used to characterise the foot and the MLA, including navicular height, was compared and then validated against the same measures taken from plain radiographs. To explore the effect of weight-bearing and non-weight-bearing conditions on the reliability and validity, measurements were made in both 10 and 90% of weight bearing. Results showed that the ICC for intratester and intertester measurements were different for 10% compared with 90% of weight bearing for all measurements. Navicular height measurement showed ICCs of 0.924 and 0.608 in 10 and 90% of weight bearing, respectively, for intertester reliability. The agreement between clinical and radiographic measurements of navicular height was reported to yield ICCs of 0.874 and 0.918 for 10 and 90% of weight bearing, respectively. Generally, absolute values of arch measurements determined clinically or radiographically, showed improved reliability and validity when normalised for foot length [10].

Direct measurement of static arch height appears to provide an objective approach to determining differences in the foot structure. The main limitation of this approach to foot classification, however, is the fact that such classification is based on static measurement of the MLA, without taking into account the dynamic behaviour of the foot. Nachbauer and Nigg [11] compared direct arch height measurement in standing and during walking and found that the amount of vertical deformation of the arch is not affected by the absolute height of the MLA.

2.2.2. Longitudinal arch angle

This angle was first described by Norkin and Levangie as the 'Feiss line' [12]. The angle is formed by a line connecting the medial malleolus to the navicular tuberosity and the most medial aspect of the first metatarsal head, and indirectly indicates the arch height. Static non-quantitative [7] and quantitative [13] measurements of the angle have been used, in combination with other parameters, to classify feet into groups of low, high, and normal. ICCs of 0.90 and 0.81 were reported for intratester and intertester reliability, respectively, in quantitative measurement [13]. This angle is suggested to compose height and length of the MLA, providing a more accurate indication of the arch behaviour [14]. The same angle as longitudinal arch angle, with a different name of ‘Supra Navicular Angle’, has been measured by employing three-dimensional analysis of marker position during running [14].

2.2.3. Rearfoot angle

This represents the angle between a longitudinal line bisecting the rearfoot (calcaneus) with the bisecting line of the distal one-third of the lower leg [13] or to the floor [15] and provides information on the frontal plane position and movements of the hindfoot. The angle may be measured directly on the subjects during standing or by mounting four markers, in pairs to represent two lines, while the subject is walking or running. The latter technique has been extensively used to evaluate the effects of different shoe and orthotic modifications on rearfoot movements [16]. Measurement of the rearfoot angle relative to the lower leg has been suggested to provide information about motion at the subtalar joint and, probably to a lesser extent, movements of the talus within the ankle mortise [13].

However, both the static rearfoot angle [17] and the arch index [17,18] have been reported to poorly correlate with the dynamic rearfoot angle. It has been suggested that the static angle of the rearfoot in single leg standing can be a clinical indicator of the degree of maximum rearfoot eversion [19].

2.2.4. Navicular drop

By assessing the sagittal plane excursion of the navicular bone during loading, the concept of ‘navicular drop’ was introduced [20]. This measurement involves locating the navicular tuberosity on the non-weight-bearing foot, which is resting on the floor with the subtalar joint in neutral position. Then the subject is asked to assume 50% weight bearing on the foot, which is in the talar head congruent position, and the sagittal plane excursion of the navicular bone is measured by a ruler.

Sagittal displacement of the navicular tuberosity may reflect excessive subtalar joint pronation, due to insufficient support of the MLA from ligaments and muscle tendons [21]. It has been also reported to indicate the degree to which the talus plantar flexes in the space on a calcaneus that has been stabilised during subtalar joint pronation [22].

Navicular drop has gained increasing acceptance during recent years. Some investigators reported this method to be a reliable means of measurement of foot pronation [15] and a valid indicator of radiographic arch height indices [23]. Navicular drop has been found to be more closely related to the pattern of rearfoot motion than traditional frontal plane measurements [24]. An excessive amount of navicular drop has been also reported to be associated with knee joint pathology [25].

Moderate intratester and intertester reliability have been reported for this measurement technique [22]. Poor reliability for quantitative measurement of navicular drop may be attributed to the relative restricted range of numerical observations for navicular displacement, as well as subjective judgement of subtalar joint position and 50% weight bearing [21].

2.2.5. Navicular drift

This concept pertains to the small amount of medial displacement of the navicular bone in the transverse plane [26]. This medial ‘drift’ of the navicular bone from neutral to resting stance position is measured in a way similar to navicular drop and may provide a quantifiable indicator of the clinically observed ‘medial bulging’ associated with the pronated foot. The only superiority navicular drift seems to have over navicular drop is that the latter indicates sagittal plane movements of the arch, whereas navicular drift reflects movements of the MLA in both the sagittal and frontal plane. The expected amount of movement from neutral to resting weight-bearing stance in the frontal plane is, however, quite small and may be too subtle to be detected using simple displacement measurements. To the best of knowledge of the authors, to date there is neither a report on the reliability of the technique, nor has there been an attempt to validate it against functional measures.

2.2.6. Valgus index

This relates the frontal plane position of the ankle joint related to the supporting surface area of the heel. The technique involves projecting the relative positions of the malleoli down onto the imprint of the supporting plantar area. The centre of the intermalleolar line is then related to a line from the centre of the heel print to the centre of the third toe print to produce the valgus index, which equals:

$$\mathrm{VI} = \frac{1}{2}AB - AC \times (100/AB)$$

A positive index is suggested to indicate a shift of the ankle medially, and a negative one a shift laterally (Fig. 1) [27].

By combining concepts of valgus index and lateral malleolar index, a modified version of the index, called the ‘malleolar valgus index’, was introduced [28]. The modification involves scanning the foot in the weight-bearing position, when the malleolar valgus index jig is adjusted to the width and height of the malleoli of each foot. The scanned image is then corrected for aspect ratio error, expressed in eight levels of grey scale and a foot coordinate system is constructed, comprising the foot width and the trans-malleolar width that are bisected and are used to calculate the malleolar valgus index.

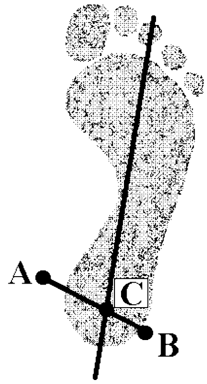

Fig. 1. Valgus index. $VA = 0.5AB - AC \times (100/AB)$ as defined by Rose et al. [27].

High interclass correlation coefficients of 0.98 (intratester) and 0.97 (intertester) have been reported [28]. However, the measurement only shows the frontal plane orientation of the ankle and no criteria of foot structure or function is taken into account in this way. The technique is suggested to be valid for static observation, but incapable of predicting dynamic foot function [26].

2.2.7. *Methods using a combination of anthropometric criteria*

2.2.7.1. Root et al. Based on the proposed 'normal joint alignment' and some functional components of foot mechanics, another method was introduced by Root et al. (Table 1) [29]. It is principally based on quantification of frontal plane components of pronation. The focus of this approach is on the neutral and resting calcaneal stance position, the subtalar joint range of motion, and the subtalar joint neutral position. As the most accepted method, it has been widely employed to evaluate foot morphology and quantify foot dysfunction. However, the reliability and validity of the technique has been questioned [22]. Invalidity may arise from the underlying assumption to the use of Root et al.'s classification model that frontal plane motions of the subtalar joint are indicators of the actual complex triplanar movements of the foot.

2.2.7.2. Sneyers et al. A combination of non-quantitative arch height measurement, based on evaluation of the midfoot contact area, and quantification of lower leg–heel alignment and forefoot–heel alignment was employed to determine the 'foot type' profile [30]. Based on these factors, feet can be divided into pes planus, pes rectus and pes cavus (Table 2). The proposed classification has been used to investigate the influence of foot malalignment on the plantar pressure pattern during running. Despite increasing sophistication, this approach still uses static rather than dynamic measurement of key measurement criteria.

Common to both aforementioned methods is using the calcaneal bisection line to define hindfoot position and motion. Recently, the reliability of clinical and calliper-based calcaneal bisection was compared on cadavers [31]. The authors reported poor intratester and intertester reliability and lack of accuracy, disproving the validity of clinical visual bisection of the calcaneus. Furthermore, two successive investigations by McPoil and Cornwall suggested that the mean path of rearfoot motion did not pass through the subtalar joint neutral position [19,24].

2.2.7.3. Jonson and Gross. The same criteria as of Dahle et al. [7], including the static longitudinal arch angle, were used to measure the reliability of arch measurement [13]. A system based on descriptive statistics (mean and S.D.) of the subjects in their study was used to quantify the measurement. A further attempt was made to measure the reliability of the proposed classification method with a reported intratester and intertester agreement of 94.4 and 88.8%, respectively. Despite high reported reliability, no attempt was made to validate this static measurement method against other functional measures.

2.3. *Footprint indices*

An imprint of the foot, provided by a simple ink pad or recently developed sophisticated pressure transducers, has been utilised to classify feet into groups. In either case, the core assumption is that any changes in the shape and orientation of structural components of the foot, collected while the subject is standing or moving, would be reflected in the imprint. Measurement of width or area of contact on the imprint is suggested to provide a simple and objective means of foot classification. Some indices and angles have also

Table 1
Foot type classification scheme based on Root et al. (from Song et al. [28])

Biomechanical examination	Planus	Rectus (normal)	Cavus
Resting calcaneal stance position (RCS)	RCS ≥ 4° valgus	2° varus ≤ RCS ≤ 2° valgus	RCS ≥ 0° varus
Subtalar joint neutral position (SJN)	Not relevant	2° varus ≤ SJN ≤ 2° valgus	SJN ≥ 4° varus
Forefoot to rearfoot alignment (FRA)	FRA ≥ 4° varus	2° varus ≤ FRA ≤ 2° valgus	FRA ≥ 4° valgus

Table 2
Criteria for classifying feet into different types based on a combination of characteristics of structure and alignment (from Sneyers et al. [30])

Criteria for classification	Planus	Rectus (normal)	Cavus
Arch height	Low	Normal	High
Leg to rearfoot alignment	Heel valgus	Neither varus nor valgus	Heel varus
Forefoot to rearfoot alignment	Forefoot varus	Neither varus nor valgus	Forefoot valgus

been introduced to evaluate the static or dynamic position of the foot while it comes into contact with the supporting surface (Fig. 2). The following is a brief explanation of some important footprint parameters.

2.3.1. Arch index

The arch index (AI) is defined as the ratio between the areas of contact of different parts of the toeless footprint. This can be used either statically or dynamically. AI, as introduced by Cavanagh and Rodgers [32], involves drawing a line from the centre of the heel to the tip of the second toe. This line is termed the 'foot axis'. A second line is then drawn perpendicular to the axis such that it is tangential to the most anterior part of the outline of the main body of the footprint in the front of the metatarsal heads. The point of intersection between these two lines is marked. Then the foot axis from the centre of the heel to this latter point is divided into three equal parts. Parallel lines drawn from each part of this line divide the toeless footprint into three areas. The AI is then calculated as the ratio of the area of the middle one-third of the footprint to the entire area (Fig. 2A). Staheli et al. [33] calculated the AI by dividing the mediolateral width of the foot in the area of the arch by the mediolateral width of the heel. A significant inverse correlation ($r = -0.70$) was found between AI, as suggested by Cavanagh et al., and arch height, as determined by direct height measurement using a calliper [34]. However, AI was reported to insufficiently explain the dynamic variation between subjects [35].

2.3.2. Modified arch index

A digital image processing approach has been employed to determine a modified arch index (MAI), which incorporates pressure data instead of geographic area of contact, as used in the AI defined by Cavanagh et al. High repeatability and reduced subjectivity in determining area have been claimed as a major superiority to AI [34]. They reported an inverse correlation of $r = -0.71$ when MAI was correlated with direct arch height measurement. High repeatability reflected by low between-day and within-day variability was reported. However, complexity of data processing is a limiting factor to this technique being widely used as a clinical tool of foot function assessment.

2.3.3. Arch (footprint) angle

The arch angle, as defined by Clarke [36], is the angle between the medial border of the footprint and the line connecting the most medial point of the metatarsal region of the footprint and the point where the shape of the inner segments of the MLA first touches the metatarsal outline of the arch (Fig. 2B). The medial borderline is the line connecting the most medial border of the metatarsal and heel region of the foot. A reliability coefficient of 0.971 was reported for measurement on 135 footprints [36].

2.3.4. Footprint index

The footprint index is defined as the ratio of the non-contact to the contact areas of the toeless footprint. The non-contact area is the part between the medial borderline of the footprint and the medial footprint outline. The contact area is the area of the footprint without the toes (Fig. 2C). On measurement of 100 footprints, a reliability coefficient of 0.982 was reported for this technique [37].

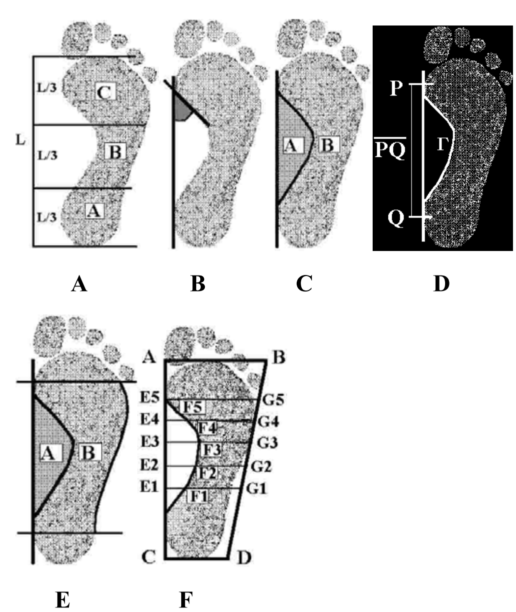

Fig. 2. Foot print parameters. (A) Arch index $= B/(A + B + C)$; (B) arch angle; (C) footprint index $= A/B$; (D) arch-length index $= PQ/r$; (E) truncated arch index $= A/B$; and (F) Brucken index = mean (EnFn/EnGn).

2.3.5. Arch-length index

The arch-length index is defined as the ratio of the length of the medial border line between the most medial points of the metatarsal and heel region and the arch length of the arch outline between these points (Fig. 2D) [9].

2.3.6. Truncated arch index

The truncated arch index is defined as the ratio of the arch area to the truncated foot area. The arch area is the part between the medial border line and medial footprint outline. The truncated area is the area adjacent to the arch area. The truncated area is bounded by the footprint area between the lines perpendicular to the medial axis of the footprint through the most medial points of the metatarsal and the heel region (Fig. 2E) [9].

2.3.7. Brucken index

The Brucken index is determined by drawing medial and lateral borders on the footprint. A series of lines (EnGn) perpendicular to the line representing the medial border are drawn and their points of intersection with the medial outline of the footprint (Fn) and the line representing the lateral border (Gn) are marked. The Brucken index is then an average of the ratios EnFn to EnGn (Fig. 2F) [38].

Footprint parameters have been widely used to classify feet into different types. It has been suggested that such an approach can provide valid information regarding the structure and function of the foot [39]. However, Hawes et al. [9] questioned the reliability of footprint parameters by comparing data obtained directly from measurement of arch height and footprint parameters. Only 4–15% of the variation in the arch height was reported to be explainable by footprint variations. They concluded that such classification represents no more than indices and angles of the plantar surface of the foot itself. More recently, McCrory et al. [40] suggested that 50% of the variance in navicular height, determined on lateral radiographs, could be explained by the measurement of arch index described by Cavanagh and Rodgers, supporting the use of arch index as a useful indirect measure of sagittal plane arch height measurement. Although McCrory et al.'s technique of height measurement on radiographs is more accurate than that of Hawes et al., the ability of arch index to predict only 50% of the variance in arch height seems inadequate to provide information regarding the medial arch structure.

A further area of limitation to the use of some footprint parameters is the inability to detect extreme low and high arch configurations. The non-contact area may be absent on imprints taken from severely flat feet and, thus, parameters like footprint index, Brucken index, and truncated arch index are not applicable. Similarly, these parameters cannot be used in high arch feet due to discontinuity of the midfoot region. Furthermore, clinicians usually encounter difficulties in using footprint measurements in significantly deformed or deviated feet.

Like anthropometric methods of classification, footprint parameters are used in the assumption that one can predict dynamic foot function through the analysis of data of structural characteristics. However, simple footprint and static arch index have been reported to be invalid indicators of dynamic rearfoot motion [41]. Hamil et al. [35] suggested that a footprint simply represents the presence or absence of foot–ground contact, and cannot provide any information regarding force or timing of plantar foot pressure.

2.4. Radiographic evaluation

Foot characteristics, including the height of the MLA, can be measured directly from radiographs taken in a standing fully weight-bearing position. Furthermore, some angles and indices are suggested to be able to represent indirectly the position of the MLA. Following is a brief explanation of the most frequently cited radiographic measures (Fig. 3).

2.4.1. Calcaneal inclination angle

From a lateral radiograph, the calcaneal inclination angle (CIA) is defined as the angle between the tangent to the inferior surface of the calcaneus and the platform on which the foot is resting [42].

2.4.2. Height to length ratio

The height to length ratio is defined as the ratio of the height to the length of the MLA where height is the distance from the platform to the inferior surface of the talar head at the distal aspect of the anterior subtalar facet. Length is the distance from the posterior surface of the calcaneus to the anterior surface of the first metatarsal head [42].

2.4.3. Calcaneal–first metatarsal angle

The calcaneal–first metatarsal angle (CI–MT1) is defined as the angle subtended by the tangent to the inferior surface of the calcaneus and the line drawn along the dorsum of the midshaft of the fist metatarsal [16]. Uniformly excellent intratester and intertester reliabilities have been reported, with correlation coefficients of at least 0.90 [23].

Radiographic measurement has been considered as a validation tool to evaluate clinical measurements, for the reason that the skeletal components of the MLA can be clearly imaged. Furthermore, foot radiographic parameters have been reported to correlate with the rate of injury [16], and a consistently high reliability has been also reported for radiographic studies by experienced examiners [23].

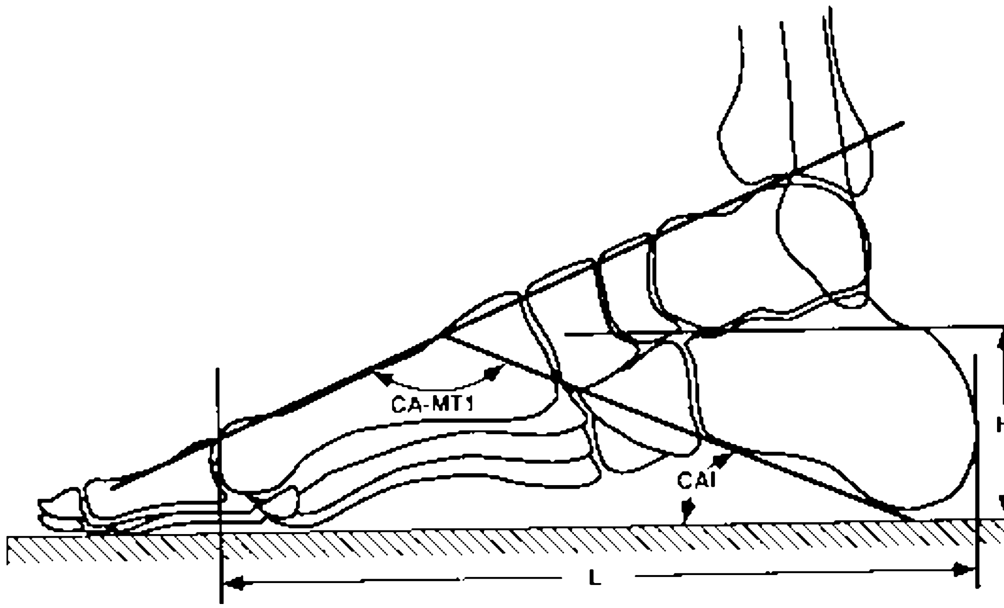

Fig. 3. Radiographic parameters defining MLA measured on standing lateral X-ray. CIA, Calcaneal inclination angle; H/L, height to length ratio; CA–MT1, calcaneal–first metatarsal angle (from Saltzman et al. [23]).

More recently, dynamic assessment using digitised videofluoroscopy measurement has been employed to determine foot function characteristics during gait with evaluation of sagittal plane motion of the medial longitudinal arch [43], and the calcaneus [44]. The CIA, CI–MT1 angle, and height-to-length ratio of the arch on radiographs and CI–MT1 determined by fluoroscopy were indicators of the foot structure. For both techniques, a high intrarater reliability was reported (ICCs of 0.99 for three radiographic, and 0.97 for fluoroscopic measures, respectively). Regardless of the static CI–MT1 angle on radiographs, fluoroscopic images showed an increase in the angle throughout stance phase of gait. This study questioned the validity of characterising foot motion based on static measures of arch shape [43].

Radiographic and fluoroscopic measurements have been consistently reported to yield a high reliability. However, the fact that they are expensive, potentially hazardous and sometimes difficult to justify for normal subjects limits their routine use as a measurement technique in clinical settings. Furthermore, both methods only provide information on two-dimensional foot structure and movement.

2.5. Measurement using criteria of foot function

Some researchers have attempted to monitor changes of foot characteristics in dynamic situations. Kayano [45] first employed an 'electro arch gauge' to investigate the dynamic function of the MLA in the foot during walking. However, no attempt was made to correlate arch measurement with other variables in the study, including the angle of first metatarsophalangeal joint, ground reaction force and electromyogram of several leg and foot muscles.

Using criteria of foot function, feet have been attempted to classify into different groups. Following is a brief explanation of some of these methods.

2.5.1. Rearfoot–forefoot angle

This angle, as defined by Freychat et al. [46], is formed between the rearfoot and forefoot axes. The positions of the posterior calcaneus, the calcaneocuboid joint, and the middle of the second and third metatarsal axes are determined on a X-ray photograph and used to define corresponding points on a footprint. Static and dynamic rearfoot–forefoot angles (αS and αR, respectively) are then defined. For the dynamic footprint, the direction of running, parallel to the runway, is marked on the sensitive paper and the angle between both rearfoot and forefoot axes and the direction of running is also measured. These angles are used as an indicator of lateral or medial orientation of the axes in relation to the direction of running. As a convention, a positive αR angle corresponds to a medial rotation of forefoot angle in relation to the rearfoot angle ('closed foot' type), and a negative value shows a lateral rotation ('open foot' type). The arch deformation is calculated by subtracting the static from the dynamic rearfoot/rearfoot angle ($\alpha R - \alpha S$) (Fig. 4). No reliability, however, is reported for the technique. The 'open' and 'closed' foot concept, as characterised by spatial orientation of the rearfoot and forefoot, can provide quantitative measurements for characterisation of the dynamic behaviour of the foot.

2.5.2. Centre of pressure excursion index

The centre of pressure excursion index (CPEI), as defined by Song et al. [28], shows the lateral displacement of the centre of pressure curve from the reference line (a line constructed between the initial and final centres of pressure values), normalised by the foot width at the anterior third of the foot. A preliminary reliability test of CPEI and angle of gait based on two independent ratings of 13 randomly selected footprints indicated good reliability (ICCs of greater than 0.95).

These techniques seem to have the potential to indicate dynamic foot function more directly than other footprint parameters that typically infer foot function from measurement of area of foot contact, and more accurately by defining the foot movements in rearfoot and forefoot segments, separately.

3. Discussion

For clinical evaluation, foot classification methods are typically based on morphology. It has been assumed that a given structural foot type will display certain functional characteristics and these, in turn, may be related to pathomechanical functions of the foot, and of the lower extremity as a whole. This model assumes that function and kinematics can be assigned to a foot mainly based on its morphological characteristics. This is the fundamental but questionable assumption underlying many clinical measurements for type classification.

Common to many models is the attempt to predict foot dynamic function by using static measurements. Recent reports, however, have questioned the reliability of clinical measurement [47], the criteria for definition of normal foot [48], and the validity of static measurements to predict foot functional behaviour [24,41].

This may explain why classification systems based on static morphological characteristics of the foot have generally been found to be poor predictors of dynamic rearfoot motion [18]. All selected ground reaction force variables, except the initial medial ground reaction force peak, are reported to be unrelated to the arch height [11]. McPoil and Cornwall [49] reported a poor predictive ability of 17 selected static measurements, including in relation to maximum pronation and time to maximum pronation.

These findings have questioned the utility of static clinical measurement of arch height as a predictor of lower extremity injury.

In one of very few quantitative studies conducted to examine the relationship between structure and function in the human foot, Cavanagh et al. [50] measured structural and functional characteristics on 50 healthy subjects during walking. Twenty-seven radiographic characteristics were used to describe foot structural features and regional plantar pressure distribution data were employed to explore the functional behaviour of the foot. Only about 35% of the variance in dynamic plantar pressure was explained by the measurements of foot structure derived from radiographs, implying that plantar pressure is influenced principally by the dynam-

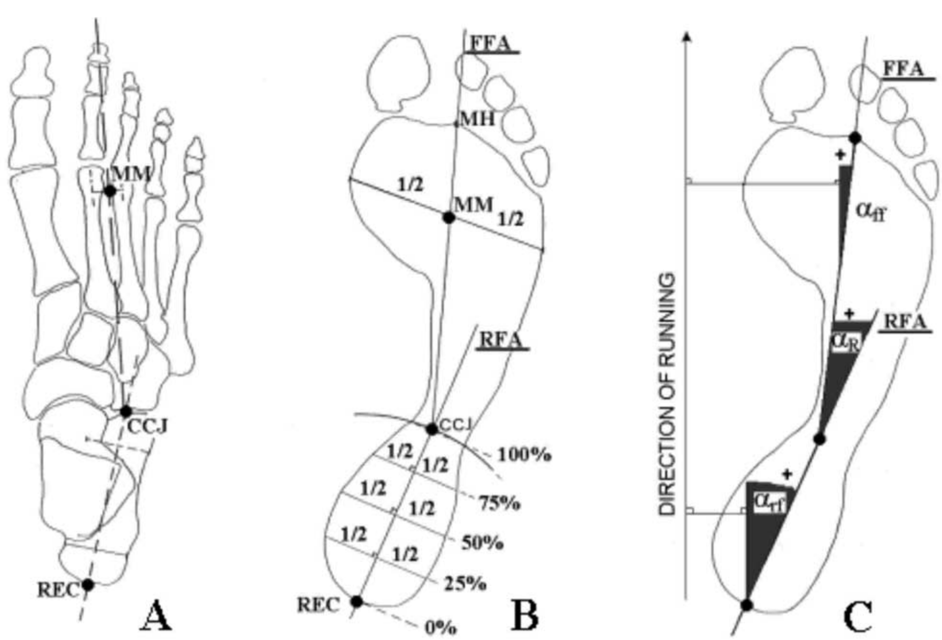

Fig. 4. Forefoot–rearfoot angle. (A) Bone and joint localisation on X-ray photographs. (B) Determination of the rearfoot (RFA) and forefoot (FFA) axes on footprint. (C) Determination of the foot angle (αR), and the rearfoot (αrf) and forefoot (αff) orientation to the direction of running (from Freychat et al. [46]).

ics of gait, and not by the structural features of the foot.

Few attempts have been made to compare parameters of the foot structure in the standing weight-bearing position with those during locomotion. Nachbauer and Nigg [11], by considering 'the height of the MLA' in the standing position and 'arch flattening' during running as two separate criteria for the categorisation of subjects into different foot type, found no relationship between arch height and arch flattening. Using the same technique, Cashmere et al. [14] reported a poor correlation between static and dynamic height of the MLA. Centre of pressure excursion index, as a dynamic foot function parameter did not show a high correlation with the static foot parameter, malleolar valgus index [28]. Static and dynamic rearfoot measurements were reported to correlate poorly to each other [17].

The ability of any type of static measurement, either structural joint alignment variables, to predict foot function has yet to be established. This casts doubt on studies in which static measurements have been relied upon to classify foot type, and to relate foot type to the incidence of injury, kinematic and kinetic variables, and to the success of orthotic intervention.

There is also a lack of normative data for many of the reported quantitative techniques, which makes the comparison of studies using similar techniques difficult. Any attempt to propose normative data and to standardise the measurement techniques would lead to more accurate and valid measurements, which helps a more efficient diagnosis and therapy of the foot and lower extremity musculoskeletal dysfunction.

Abnormal foot configuration, and the MLA in particular, has been reported to be associated with various injuries of the lower extremity in running, making the use of a reliable and valid measurement technique of crucial importance.

There is an encouraging tendency among clinicians and researchers to now use measurement techniques, which have the capacity of functionally evaluating subjects while walking or running. Using three-dimensional kinematic, force plate, and foot pressure measurements it is hoped to strengthen validity of such measurements. Further research is needed to evaluate the use of such classifications on large groups of subjects with different foot types, both in normal and pathologic conditions.

4. Summary

Although clinical evidence suggests a relationship between foot structure and musculoskeletal injury pattern, attempts to explore the actual effect of the foot structure on the occurrence of injury produce conflicting findings.

To evaluate such possible effects, different methods have been used to classify feet, most of which are based on static morphological characteristics. Furthermore, the majority of these techniques demonstrate the static structural features of the foot, with no proven relationship between variable structure and abnormal biomechanical behaviour.

Results of rare attempts to correlate the foot structural characteristics to foot function have shown poor predictive ability based on foot structural features. Investigations into the effect of such structural variability on kinematic, ground reaction force components, and plantar pressure pattern variables have also reported controversial findings, probably due to the use of different classification methods. Despite the fact that clinicians regularly perform static lower extremity measurements on their patients, little research to date has been published supporting their ability to predict dynamic foot function. It seems that common methods of foot type classification lack an overall ability to predict susceptibility of a given foot structure to injury. If a specific structural or joint alignment feature based on static measurement is to be used for foot classification, a correlation has to be established between static foot structure and dynamic foot function. Until then, an ideal method of classification must measure foot characteristics, either structural or alignment features, and ideally a combination of both, under dynamic conditions.

Acknowledgements

The authors would like to thank the Ministry of Health and Medical Education, Islamic Republic of Iran, and the Faculty of Rehabilitation, Shiraz University of Medical Sciences, Shiraz, Iran for the financial support of the studentship toward this project.

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