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The relationship of abnormal foot pronation to hallux abducto valgus — a pilot study

F. D. ROSS

School of Chiropody, Edinburgh

Abstract

Abnormal foot mechanics is the most common cause of hallux abducto valgus. To date no quantitative data regarding the relationship between abnormal foot mechanics and the degree of hallux abducto valgus has been presented. An outline of the abnormal foot mechanics responsible for hallux abducto valgus is described along with a technique for measuring the extent of abnormal function. A common intrinsic abnormality responsible for hallux abducto valgus is described along with its diagnosis and orthotic treatment.

Introduction

Abnormal foot mechanics is the most common cause of hallux abducto valgus (Burns 1979). Until the advent of podiatric biomechanics in the early 1960's abnormal foot mechanics, as an etiological factor of hallux abducto valgus, had received comparatively little attention in the literature. A tendency for a pronated foot to develop hallux abducto valgus has been reported in several papers (Stein, 1938; Galland and Jordan, 1938; Joplin, 1950; Craigmile, 1953). Hofmann (1905) stated that a pronated foot is always associated with, and is always the cause of hallux abducto valgus. Studies describing the incidence of hallux abducto valgus in shod and unshod populations have identified footwear as an important etiological factor (Lam Sim-Fook and Hodgson, 1958; Shine, 1965). Several authors however, have reported that hallux abducto valgus occurs in unshod persons (Lam Sim-Fook and Hodgson, 1958; Shine 1965; Mann and Coughlin 1981). Root et all (1977) suggest that shoes are not a cause of hallux abducto valgus but aggravate the condition and accelerate the onset of deformity in a foot that exhibits abnormal foot mechanics.

All correspondence to be addressed to Mr. F. D. Ross, 6 Greengates, High Street, Henley in Arden, Warwickshire, England.

In a review of the literature available no quantitative data regarding the relationship between abnormal foot mechanics and hallux abducto valgus, in shod or unshod individuals, has been presented.

The purpose of this pilot study was to establish a quantitative method of measuring the abnormal foot mechanics associated with hallux abducto valgus. Subsequent work using the established technique would allow quantitative data to be collected and a possible correlation identified between abnormal foot mechanics and the incidence of hallux abducto valgus. An outline of the abnormal foot mechanics responsible for the development of hallux abducto valgus is given. The technique used to determine the magnitude of abnormal foot mechanics is described and an indication for its possible use is suggested. Clinical data regarding the incidence of non-rigid forefoot valgus, the most common predisposing frontal plane forefoot variation, responsible for the development of hallux abducto valgus is presented. The treatment of a non-rigid forefoot valgus condition using functional biomechanical orthoses is described.

Normal foot function

Before describing the abnormal foot mechanics associated with hallux abducto valgus it is necessary to discuss certain aspects of normal foot function.

At heel strike the subtalar joint should be neutral to slightly supinated. At 25 percent of the stance phase the subtalar joint is in a slightly pronated position, unlocking the midtarsal joint allowing adaptation to uneven terrain and providing shock absorption to the foot and skeletal superstructure. At this point the midtarsal joint is supinated from its fully locked position against the hindfoot and the first ray is in a dorsiflexed position. At 50 percent of stance phase the subtalar joint is approximately neutral. At this time the midtarsal joint should be fully pronated and locked against the hindfoot. At 75 percent of stance phase shortly after the heel comes off the ground the midtarsal joint remains locked against the hindfoot and the oblique toebreak, along with plantarflexion of the first ray, allows the forefoot to stay in contact with the ground. Plantarflexion of the first ray is important to allow free dorsiflexion of the hallux. Subtalar joint supination is primarily responsible for stabilizing the first ray during propulsion.

Abnormal foot function associated with hallux abducto valgus

Hallux abducto valgus is generally an acquired condition resulting in subluxation of the first metatarsophalangeal joint. The subluxation of the first metatarsophalangeal joint and subsequent development of a hallux abducto valgus deformity is caused by hypermobility of the first ray during the midstance and propulsive phases of the gait cycle. Hypermobility of the first ray occurs when the subtalar joint remains in a pronated position during midstance and propulsion. Subtalar joint pronation occurring during midstance and propulsion is classed as abnormal. The extent of first ray hypermobility and first metatarsophalangeal deformity is directly proportional to the degree of abnormal subtalar joint pronation. In order for hypermobility of the first ray to produce hallux abducto valgus deformity, it is necessary for the predisposing factor of forefoot adductus greater than 15° to be present. Abnormal pronation produces an abnormal position of the first metatarsal head during propulsion. The first metatarsal assumes a dorsiflexed and inverted position relative to the rest of the metatarsus as the first ray moves around its normal axis of motion. Therefore as muscles attempt to hold the hallux firmly against the ground, the first metatarsal head rotates into a dorsiflexed and inverted position relative to the base of the proximal phalanx. The normal first metatarsalphalangeal joint does not have an axis that allows motion to occur in a frontal plane. When the first metatarsophalangeal joint is forced to move in a frontal plane, contrary to its plane of motion, the joint subluxes.

In addition there is a functional lateral displacement of the sesamoids. Lateral displacement of the sesamoids gives the short flexor apparatus an advantage in an abductory direction and the dorsiflexion of the first metatarsal limits first metatarsalphalangeal joint dorsflexion, enhancing the likelihood of the hallux displacing laterally. Once lateral displacement of the hallux has begun the development of deformity is enhanced by several factors, two of these are: the bowstring effect of the long flexors inserting into the hallux; and the inherent digital abductus.

There are several predisposing abnormalities which cause abnormal pronation. One of the most common of these is non-rigid forefoot valgus (Burns 1977). The majority of these abnormalities inhibit normal resupination of the subtalar joint and maintain the foot in a pronated position throughout the midstance and propulsive phases of gait and therefore may cause the development of either hallux abducto valgus or hallux limitus (Fig. 1).

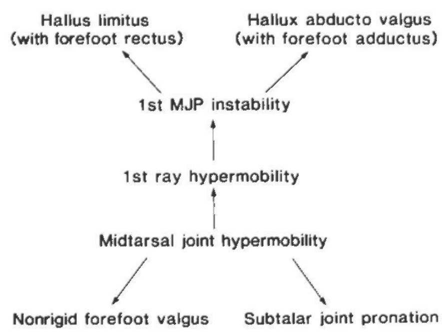

Fig. 1. Flow chart of hallux abducto valgus formation.

Measurement of foot pronation during midstance in an appropriate number of individuals would provide quantitative data to determine whether abnormal pronation was a consistent etiological factor in hallux abducto valgus. It will be remembered from the discussion of normal foot function that the foot should be in a neutral position at midstance.

Introduction to methodology

Vertical displacement of the navicular bone occurs with subtalar joint pronation. The magnitude of the vertical displacement of this prominent anatomical landmark when going from a non-weight-bearing to a weight-bearing stance was selected as a measurement of foot pronation.

Human gait is a highly complex dynamic event involving several anatomic structures both intrinsic and extrinsic to the lower extremity. Gait analysis however, may be simplified by considering static situations. For example the midstance phase of gait can be approximated by one leg static stance (Black and Dumbleton, 1980) the utilization of static equilibrium situations provides a basic understanding for the determination of joint position and the principles behind joint motion.

Even where the dynamic aspects are important a static analysis is usually the first step in the solution of the most involved mathematical and physical problems (Fender, 1962).

For the purpose of this pilot study a foot which displayed the following features in a static weight-bearing situation was designated a pronated foot: the height of the medial longitudinal arch was decreased and the forefoot was abducted on the rearfoot.

Method

Fifteen individuals (10 females, 5 males) aged 19-33 years (mean age 20 years) with varying degrees of hallux abducto valgus (8-32 degrees; mean 16 degrees) were used for the study.

The magnitude of hallux abducto valgus was obtained by the following method.

1. A foot print was obtained for each subject in right foot unipedal stance using an inked pedogram.

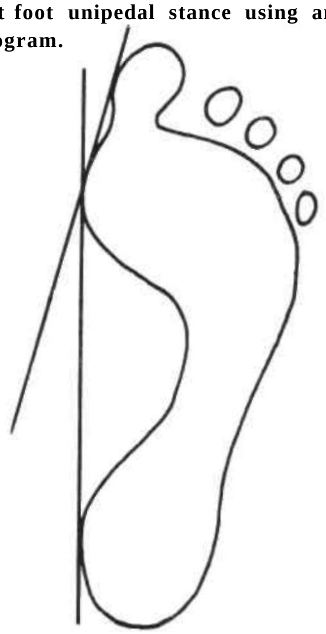

Fig. 2. The method used to measure hallux abducto valgus.

Fig. 3. Palpating the congruity between the neck of the talus and the calcaneus when determining subtalar neutral.

2. On the resultant pedograph the medial border of the foot was represented by a line drawn tangent to the first metatarsal phalangeal joint and the calcaneus.
3. From the tangent point of the first line at the first metatarsphalangeal joint a second line was drawn tangent to the medial border of the hallux.
4. The angle measured in degrees created by these two lines represented the extent of the hallux abducto valgus deformity (Fig. 2).

Navicular differential

The position of the navicular bone was determined with the foot in weight-bearing and non-weight-bearing positions.

The subtalar joint was placed in neutral and the midtarsal joint was fully pronated in the right foot of each subject. Neutral subtalar joint position can be ascertained by palpating the relationship of the head and neck of the talus to the calcaneus just anterior to the melleoli (Fig. 3). Neutral position should be defined as that position at which the subtalar joint is most congruent and neither the medial or lateral heads of the talus can be felt.

The right navicular was identified by palpation and marked with ink. For the non-weight-bearing position the subject was seated in a chair with both feet resting on the ground. Before sitting the subjects assumed their natural angle and base of gait. This meant that the right foot would be viewed in its natural midstance attitude. To obtain the natural angle and base of gait the subjects walked on the spot for approximately one minute at a comfortable pace with eyes straight ahead. They were then commanded to stop rapidly. The resultant position of the feet was taken to represent the natural angle and base of gait.

Without moving their feet the subjects were seated. The chair height was adjusted until both knees were flexed 90°. This ensured that the legs were perpendicular to the ground and the tibiotalar joints were in their neutral position. The non-weight-bearing height in millimetres was measured from the floor "to the ink spot on the right navicular bone. It was decided that placing the ankle joint complex in neutral was necessary to obtain a true indication of non-weight-bearing navicular position; the relationship of the foot to the ground is dependent on the relationship of the hindfoot to the ground. Maintaining the angle and base of gait the subjects then stood and the bipedal weight-bearing height (WB-2) of the right navicular was measured. The height for weight-bearing on the right foot only (WB-1) was then found. As in previous research the difference between the non-weight-bearing and weight-bearing measurements was identified as the navicular differentials (Delacerda 1980 a/b).

Table 1. Navicular differentials in feet with varying degrees of hallux abducto valgus.

Navicular differentials		Hallux abducto valgus
WB-2	WB-1	Degrees
25	27	32
12	18	30
14	18	5
12	16	15
13	15	18
9	14	21
12	14	20
10	13	18
8	13	12
10	12	17
9	12	16
10	12	14
8	12	13
7	9	9
4	7	8

Discussion

The vertical displacements of the right navicular bone of each subject are respresented in Table 1. The WB-1 Navicular Differential was greater than the WB-2 in all fifteen subjects.

The third subject also exhibited a hallux limitus in the right foot. This is because the angle of inherent forefoot adductus can vary from 0°-90°, thus, there is a point at which both deformities may occur simultaneously. In general an abnormal foot with a forefoot adductus angle in excess of 15° primarily develops a hallux abducto valgus deformity, while one with 10° or less of forefoot adductus primarily develops hallux limitus (Root et al, 1977). The abnormal pronation displayed by the third individual primarily predisposed to the development of hallux limitus.

To date, there is scarcely any evidence in the literature to suggest that static and dynamic function of the lower extremity are well correlated. Thus it may be the case that a patient presenting certain appearances during static examination functions entirely differently during walking. It is possible, therefore, that the WB-1 navicular bone displacement measured in an individual could be greater or smaller during walking. This factor was recognised as a limitation of this study.

However with the exception of the third result it would appear that within the limits of this study, abnormal pronation, as determined by the navicular differential at midstance was a consistent factor in the incidence of hallux abducto valgus.

Further study

Further clinical data is being collected in an attempt to establish a significant correlation between abnormal subtalar joint pronation and hallux abducto valgus.

As a control it is hoped to replace both the pedogram and navicular differential methods with X-ray analysis enabling exact measurement of hallux abducto valgus and navicular bone displacement. It would then be possible to determine how accurate the pedogram and navicular differential techniques are as a quick clinical method of measuring abnormal pronation.

Proposed use of navicular differential

In addition to the extent of hallux abducto valgus the speed of onset of this deformity is directly proportional to the degree of abnormal subtalar joint pronation. In this respect a quantitative measurement of a patient's abnormal subtalar joint pronation would provide an objective indication of the urgency, intensity and type of treatment required for that individual.

Abnormal pronation of the foot is one of the most common postural deformities seen in the feet of weight-bearing children (Tax, 1980). In the average individual adult, morphology of the foot is closely approximated by seven to eight years of age. Only a small change in arch height and morphology occurs in the normal foot from eight years of age to full maturity (Root et al, 1977). The abnormal foot function associated with hallux abducto valgus in children is similar to that found in adults. When abnormal pronation, joint hypermobility and subluxation occurs prior to the age of seven it generally retards or stops normal osteogeny and results in severe deformity of the foot. For this reason Tax (1980) states that abnormal pronation should be treated as early as possible using functional biomechanical orthoses.

This paper proposes that the navicular differential technique offers a quick and easy quantitative method of evaluating abnormal foot pronation in a clinical situation.

Forefoot valgus

A forefoot valgus is any forefoot to hindfoot mechanical relationship in which the plane of the forefoot (represented by a line drawn through the plantar aspect of the first and fifth metatarsal heads) is everted relative to a line bisecting the posterior aspect of the calcaneus when the subtalar joint is in a neutral position and the midtarsal joint is fully pronated and locked (Fig. 4, left).

The type of abnormality described above is classed as a frontal plane forefoot variation. Forefoot valgus can be subdivided into two groups; rigid and non-rigid.

Approximately 70 percent of all frontal plane forefoot variations are valgus. This observation is based on a review of the examination of 276 patients representing 552 feet. In this study by Burns (1977) significant frontal plane forefoot variation was found in 56 percent of the feet (309 feet) of these, 70 percent were forefoot valgus (216 feet). Burns also found that 70 percent forefoot valgus were of the non-rigid type. This means that nearly one half of all frontal plane forefoot variations are non-rigid forefoot valgus. Non-rigid forefoot valgus causes abnormal subtalar joint pronation, and therefore can cause hallux abducto valgus.

In a non-rigid forefoot valgus medial loading of the forefoot in a plane perpendicular to the posterior bisection of the calcaneus, causes the first ray to dorsiflex and the midtarsal joint to supinate bringing the plane of the forefoot perpendicular to the heel and unlocking the midtarsal joint relative to the hindfoot (Fig. 4, right).

Forefoot loading similar to that described above occurs during midstance and propulsion creating hypermobility of the midtarsal joint and first ray. The subtalar joint generally functions around a pronated position in this foot type to accommodate the supinated forefoot.

Midtarsal and first ray hypermobility caused by a non-rigid forefoot valgus in a foot with a metatarsus adductus greater than 15° can cause hallux abducto valgus.

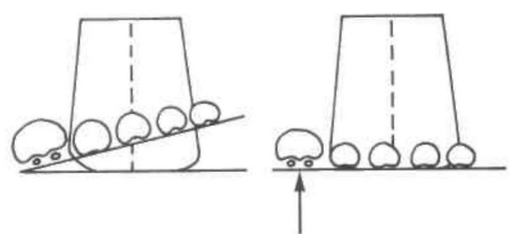

Fig. 4. Left, non-rigid forefoot valgus. Right, the effect of loading the medial aspect of the forefoot perpendicular to the bisection of the heel.

Orthotic therapy

Hallux abducto valgus is commonly caused by abnormal subtalar joint pronation in a foot exhibiting forefoot adductus in excess of 15°. In order to prevent the development of this type of hallux abducto valgus abnormal subtalar joint pronation must be eliminated. In a study involving six individuals both the period of pronation and the amount of maximum pronation were significantly reduced using functional biomechanical orthotic devices (Bates et al, 1979). Root et al (1977) state that hallux abducto valgus deformity can either be decreased or its development arrested by treatment with functional orthoses.

Manufacture of orthosis

A functional orthosis for a non-rigid forefoot valgus comprises a hindfoot post (Wedge) to control abnormal pronation of the subtalar joint and a 2-5 metatarsal bar post to enable equal loading of the forefoot.

A negative slipper cast of the foot is taken with the subtalar joint in neutral positions and the midtarsal joint fully pronated. The positive cast is poured and once dry is removed from the negative. It is then rubbed down with fine sandpaper.

The weight-bearing points of the first and fifth metatarsophalangeal joint are established by gently rubbing the positive cast against the worktop. Marks are then made 1cm proximal to these points which will represent the most distal edge of the orthosis shell. The first and fifth metatarsal shafts are bisected and these lines represent the medial and lateral borders of the orthosis respectively (Fig. 5, left).

One of the most common materials used in the manufacture of functional biomechanical orthoses is Plexidur. This is preheated and vacuum formed to the positive cast. Excess material is removed until the shell of the orthosis conforms to the marks on the positive cast. The shell is then cut back from the medial aspect of the second metatarsal head to a point approximately 1.5 cm proximal to the first metatarsal head (Fig. 5, right).

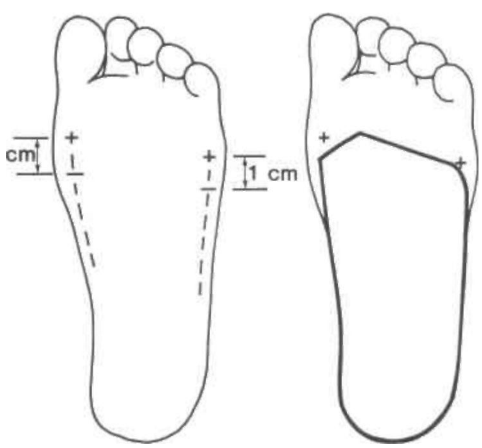

Fig. 5. Left, marking of first and fifth metatarsal heads. Right, shape of finished shell.

Next, the hindfoot post and the 2-5 metatarsal bar post are incorporated into the shell of the orthosis. Before posting the orthosis the shell is

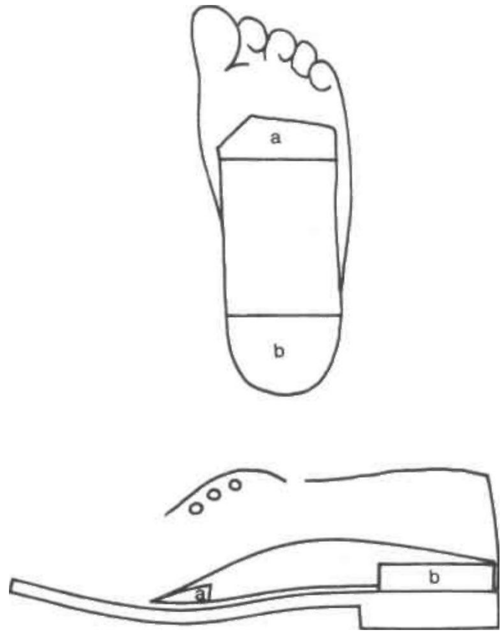

Fig. 6. Plastic shell fabricated as described in text, a) metatarsal bar post, b) medial hindfoot post.

secured to the positive cast with zinc oxide tape. Both of these additions are made from acrylic resin. A 2mm thick bar post is placed along the anterior edge of the shell from the second to fifth metatarsal heads.

The hindfoot post is applied in the following manner. A quantity of acrylic is placed on grease proof paper on the worktop. The shell is then pushed into the acrylic and angled in the frontal plane raising the anterior medial edge of the device from the supporting surface. The shell is angled 4° and this is checked by placing an angle finder on the dorsal surface of the positive cast. Once dry, excess acrylic is removed with a grinding wheel until the posts conform to the dimensions of the shell. Finally the hindfoot post is given a 4° grind off to allow for normal pronation of the subtalar joint during the stance phase of the gait cycle. A functional orthosis sits in the patient's shoe and is not secured to the foot in any way (Fig. 6). The effectiveness of the orthosis can be augmented by wearing lacing type footwear with a stiff heel counter and shank, and a deep heel seat. The aim of functional orthoses control is to allow the foot to heel strike with the subtalar joint near the neutral position, to pronate for shock absorption and then allow transverse plane rotation of the leg. The pronation must be controlled and limited so that the foot will be in a position from which it can resupinate. By 50 percent of the stance phase of gait (mid-stance) when the subtalar joint is back near its neutral position, the orthosis must maintain the midtarsal joint fully pronated against the hindfoot in preparation for propulsion. By 75 percent of stance phase the foot should be rigid for its use as a lever during propulsion. At this time the orthosis has little effect on the foot as propulsive forces are concentrated distal to the device. The normalization of function which the orthosis provides up to this time allows the foot to be in a position from which adequate propulsion is possible.

The principle of functional orthosis therapy for a non-rigid forefoot valgus is to prevent abnormal subtalar joint pronation. This prevents midtarsal joint and first ray hypermobility during midstance and propulsion and eliminates the development of hallux abducto valgus. Functional orthosis therapy increases the plantarflexion force exerted by the peroneus longus muscle during propulsion thus enhancing first ray stability. In addition a functional orthosis provides stability of the forefoot around the oblique axis of the midtarsal joint.

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