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Review

Footwear and orthopaedics

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ABSTRACT

Footwear is the oldest known fashion accessory in use. Footwear is often implicated in orthopaedic problems affecting lower limbs and back. Hence footwear modifications have a major role in management of these pathologies as well. This review explores footwear and its role in causation and management of orthopaedic problems. Based on our observations we recommend that children with flexible flatfeet should be encouraged to walk barefoot to help in developing their arches. Women with risk factors for secondary arthritis of knee or back pain may be advised to avoid heels. Commercial shoes which decrease hind foot loading may be used in symptomatic management of hindfoot and mid foot problems. Similarly shoes which decrease forefoot loading may be useful in managing forefoot pathology. Flip-flops should be avoided by diabetics as they do not protect from injuries.

Contents

This review explores footwear and its association with orthopaedics. It discusses the evolution of footwear, the association of orthopaedic pathology with footwear and the use of footwear in the management of orthopaedic problems.

1. The evolution of footwear

Footwear was in use by at least the middle Upper Palaeolithic era (the Stone Age as it is more commonly called) in parts of Europe, based on archaeological evidence [1]. This has been suggested following comparative biomechanical analysis of the proximal phalanges in feet of western Eurasian Middle Upper Palaeolithic humans and those of variably shod recent humans. Spanish cave drawings from 15,000 years ago show humans with animal skins or furs wrapped around their feet. The oldest footwear was recently recovered from a cave in Armenia [2] and has been

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dated to be 5500 years old. In Egyptian funeral chambers (around 3000 BC), paintings show the different stages in the preparation of leather and footwear, but although the history of footwear may appear long, it is only a very small part of our evolution since Homo Sapiens appeared on earth 200,000 years ago.

Even though footwear has such a long history, there has not been a significant change in appearance. Sandals, the oldest known footwear, are still in use. Platform soles can be traced back to 16th century. There are references and depictions of high heels back to well before Christ's time, when Egyptian butchers wore high heels to stay above the messy butcher's shop floors. Initially shoes were made in the shape of the foot. Over time, shoes became decorative items and symbols of status and vanity. As the shape of shoes changed, they became deforming forces on the foot and a source of pain. Examination of skeletal remains from earlier and later medieval periods has shown that the incidence of hallux valgus increased with the practice of wearing narrow pointed shoes during the latter [3].

2. Types of feet

There are broadly three types of feet. The Egyptian type (the commonest) has a great toe longer than second, the Greek type has a second toe longer than the first and the Square type has great and second toes of same length. Egyptian feet have been incriminated in hallux valgus [4], hallux rigidus [5] and ingrowing toe nails [6]. Greek type feet (also known as Morton's type [7]) may be associated with higher risk of metatarsalgia, hammer-toes and Morton's neuroma (Fig. 1).

3. The effect of footwear on gait

Dusing and Thorpe [8] found in their study of 438 children that the mature gait pattern is well established in most children by the age of 7 years (although may be delayed up to 13). The medial arch also appears by the same age. Lythgo et al. [9] found that children and young adults walking with footwear had increased gait speed, step length, stride length and support base but reduced foot progression angle and cadence compared to those walking barefoot. Their short steps allow the feet to land on the heels, then roll over the lateral column and finally a push off with the toes, all encouraging intrinsic muscle activity. By contrast, when walking on shoes with stiff soles there is hardly any intrinsic activity.

Footwear also influences movement patterns in feet during walking. Shoes restrict forefoot eversion by 20% compared the eversion seen during barefoot walking. During push-off, shod walkers consistently showed forefoot inversion, whilst barefoot walkers showed varying amounts and degrees of torsion [10]. Footwear also constrained forefoot spreading and foot pronation during push off. Stiffer shoes naturally caused more restriction of movement.

Running shoes were only first designed as recently as the 1970s. Barefoot runners typically land on their forefoot or midfoot and shod runners land on their heels which are protected by the elevated, cushioned heel part of their shoe [11]. Interestingly, kinematic and kinetic analyses show that barefoot runners generate smaller collision forces than shod runners, even on hard surfaces.

4. The effect of footwear on feet

Shoes have been implicated as a causal factor in a great many foot pathologies. In a survey of 1846 skeletally mature people, Sachithanandam and Joseph found that the prevalence of flatfeet was higher in those who started wearing shoes before the age of six [12]. Similarly, Rao and Joseph showed a prevalence of flatfoot of 8.6% in shod versus 2.8% in unshod children [13]. Pes planus was most common in children who wore closed-toe shoes, less common in those who wore sandals or slippers, and least common in the unshod. In light of this evidence, children with flexible flatfeet may be advised to walk barefoot whenever possible, rather than wearing shoes with inserts to support the arch.

Under-sized footwear has been shown to increase the hallux valgus angle in children [14]. Wearing shoes substantially narrower than the foot is associated with corns on the toes, hallux valgus deformity and foot pain, whereas wearing shoes shorter than the foot is associated with lesser toe deformities. In another study, wearing shoes with a heel elevation greater than 25 mm was associated with hallux valgus and plantar calluses in women [15]. An American Orthopaedic Foot and Ankle Society survey on women's shoes in 1993 showed that majority of women wore shoes that were smaller than their feet [16]. The incidence of footpain and deformities were found to be higher in women wearing smaller shoes than those not. Wearing smaller shoes with high heels also tightens up the windlass mechanism [17,18] resulting in abnormal forefoot loading which could in turn contribute to forefoot pathology. Women should be advised to get their feet measured regularly and wear properly sized shoes.

5. Footwear and proximal joints

Walking barefoot has been shown to reduce the loading in osteoarthritic knees significantly [19]. Kerrigan et al. showed that high-heeled shoes increased loading in patello-femoral and medial

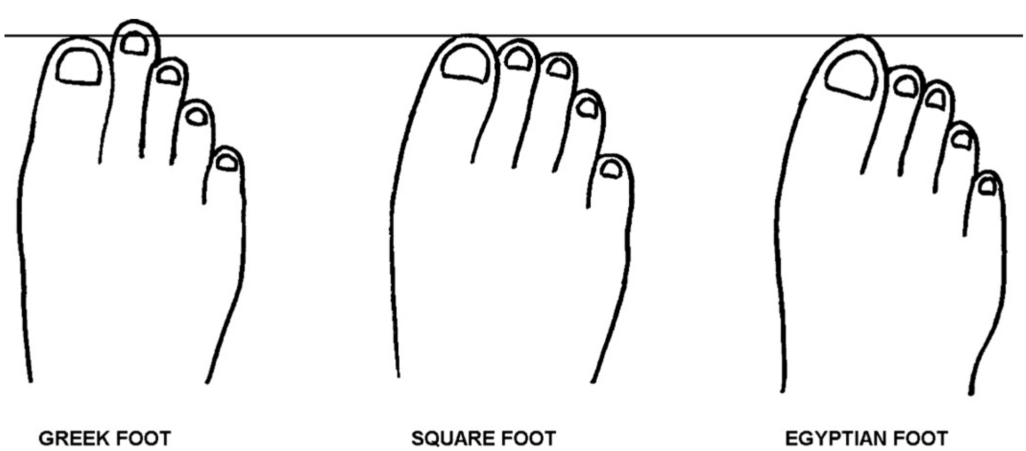

Fig. 1. Foot types – Greek, Square and Egyptian.

compartments of the knee by as much as 23% compared to walking barefoot [20]. This increased loading was observed in both wide-heeled and narrow-heeled shoes [21]. High heels therefore may be one of the factors contributing to the higher prevalence of knee osteoarthritis in women. Improper shoe use has been incriminated in patello-femoral pain in runners [22]. In light of this evidence, women with risk factors for early arthritis (previous trauma, meniscectomy etc.) may be advised against wearing heels.

Footwear also increases joint loading in the hip. Bergmann et al. studied hip loading in a patient who had a joint prosthesis that functioned as a force transducer [23]. They obtained direct force measurements from the transducer and demonstrated that there were no differences in hip loads among nearly 15 different types of shoes, but the hip loads were significantly lower when the subject was barefoot.

The literature is unclear on the effect of high heels on the lumbar spine and posture. The common belief is that high heels increase lumbar lordosis. However, Opila et al. showed that wearing high heels caused lumbar flattening, a backward tilting pelvis, a reduction of the distance of the knee and ankle from the centre of gravity, and a posterior displacement of the head and thoracic spine [24]. Similar findings were also noted by Bendix et al. and de Lateur et al. [25,26]. The reduction of lumbar lordosis in time may cause back pain. Women with lumbar spine pathology (such as degenerative disease) may be advised to avoid heels if it helps their symptoms.

6. Footwear and injuries

Heelies (shoes with a wheel embedded into the heel) have become very popular with children and have been shown to cause increased incidence of injuries [27,28]. These injuries may be avoided by the use of protective gear, as advised by the manufacturers.

Shoe wear has been shown to predispose to lateral ligament injuries of the ankle by inhibition of the normal proprioceptive feedback mechanisms [29]. Shoes also limit the adaptive pronation during foot-strike in running and leave the foot more prone to injuries in a supinated position [30]. However, different shoe designs have not been shown to influence sport-related ankle sprain rates [31].

7. Footwear modifications for orthopaedic pathology

7.1. Heel modifications

The heel can be elevated by an insert or by external shoe modifications. External raises have the advantage of not raising the heel out of the counter, and therefore allow better grasp of the heel. Lateral heel wedging (posting) has been shown to decrease pressure under the third, fourth and fifth metatarsals and medial heel wedges correspondingly decrease pressure under the first and second metatarsals [32]. Shoe modifications have also been shown to be a simple, inexpensive and effective tool in the conservative management of knee osteoarthritis [33]. Lateral wedges inside shoes are effective in medial compartment osteoarthritis of the knee by decreasing the peak varus moment at the joint, particularly in patients with early disease [34,35]. Similarly medial wedges have shown promising results in lateral compartment disease of the knee [33].

7.2. Orthoses

An orthosis may be defined as ‘an externally applied device, which modifies function by supporting or controlling a body part’. In-shoe orthoses (or orthotics) are devices placed inside a shoe to accommodate anatomical abnormalities, to relieve pressure at a specific site or to alter the transmission of forces during gait. They work by applying force in a controlled manner and may be accommodative or corrective devices. Arch supports are used in the symptomatic treatment of idiopathic flatfeet, midfoot arthritis, and tibialis posterior dysfunction. For optimal benefit they are custom made for individual patients.

7.3. UCBL

UCBL (University of California Biomechanics Laboratory) inserts have been in routine use for the symptomatic treatment of flexible flatfeet in children and adolescents for a long time [36]. The device corrects heel valgus, thereby stiffening the transverse tarsal joints and diminishing pronation and forefoot abduction. They seem to reduce symptoms in flatfeet, albeit with no effect on the underlying pathology [37]. However, the effects of these inserts on feet remain essentially unproven.

7.4. Over-the-counter inserts

Many companies offer over-the-counter padded insoles for shock absorption and heel cushioning, claiming relief from many common foot problems. The most popular types include viscoelastic heel cushions for plantar fascitis and metatarsal supports for metatarsalgia, both of which have been shown to be successful treatment options [38,39]. In treatment of metatarsalgia, Hsi et al. showed that for optimum pressure reduction, the metatarsal pad has to be positioned just proximal to the metatarsal head [39].

8. Commercial footwear for orthopaedic problems

The observation that barefoot walking is more biomechanically efficient than shod walking has prompted manufacturers to design footwear, which mimics barefoot walking itself. The most popular commercial shoes in the market claim to create an ‘unstable’ gait [40]. Stable and unstable gaits have never previously been defined in the literature, but we hypothesise that the three rockers of natural gait are ‘unstable’, compared to the ‘stable’ gait with a rigid soled shoe and no rockers. Commercially available ‘unstable’ shoes reportedly make the gait ‘unstable’ by using a rocker. It is possible that similar effects can be achieved by barefoot walking as well.

9. MBT® shoes

MBT (Masai Barefoot Technology)® shoes are currently one of the most popular in the market. The manufacturers claim that these shoes work on the principle of ‘natural instability’. MBT’s patented sole construction, the soft Masai sensor, is claimed to simulate walking and standing on uneven ground. This reportedly stimulates the body to activate its natural balance mechanisms, thus strengthening the supporting, shock absorbing muscle groups in the body from the legs to the back. The manufacturers themselves suggest that similar effects can be achieved by walking barefoot on soft, uneven, natural ground such as sand and moss.

The unstable shoe has been shown to produce changes in kinematic, kinetic and electromyographic characteristics in lower limb muscles that seem to be advantageous to the locomotor system [40]. MBT shoes have been shown to significantly reduce pressure under the hindfoot (11% reduction) and midfoot (21% reduction) and to transfer the same to the forefoot (increases by 76%) [41]. By reducing hindfoot and midfoot loading they have been shown to be beneficial in diabetics with neuropathy, although similar foot pressure reductions have also been observed with the use of simple rocker soles [42,43]. MBT shoes have also been shown to reduce loading at the knee and hip joints, improve symptoms from knee

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Fig. 2. Example of MBT® shoe (published with permission).

Fig. 4. Fitflop™ (a flip-flop) (published with permission).

osteoarthritis and reduce back pain symptoms in golfers [44,45]. It is quite possible that most of the effects of these unstable shoes can be attributed to the rocker sole alone.

With the available evidence it appears that rocker bottom shoes may be beneficial for hindfoot and midfoot problems but may be best avoided in patients with forefoot pathology (Fig. 2).

10. Earth® shoes

The defining feature of earth footwear is the so-called 'Negative Heel Technology' – an inclined sole that positions the toes 3.7° higher than the heels. This slight angle shifts weight subtly back over the heels, and is claimed to help strengthen muscles whilst also burning calories. All earth footwear also has reinforced support through the arch, which claims to maximize the effectiveness of the heel design in promoting a natural walking motion. Additionally, all earth shoes contain a form-fitting footbed that moulds to the shape of the foot, displacing and absorbing shock with each step. Users have described the experience as like 'walking on an inclined treadmill'.

Katy Bowman [46] of the Restorative Exercise Institute (unpublished study) conducted a study of 31 healthy women divided randomly into two groups: one walked in earth footwear and the other walked in a conventional heeled alternative. After walking 10,000 steps, three times per week for four weeks, the earth footwear group were found to burn fat faster and lose more weight. In contrast, Mann et al. found that earth shoes did not affect the gait pattern of subjects tested on gait analysis, force plate analysis and EMG studies. The subjects also complained of increased heel pain during the study period [47].

If these shoes do reduce pressure under forefoot as claimed, they are likely to be beneficial for forefoot pathology such as hallux rigidus and metatarsalgia, but are to be avoided in patients with hindfoot problems such as plantar fascitis (Fig. 3).

Fig. 3. Example of earth® shoe (published with permission).

11. Flip-flops

Flip-flops also are claimed to simulate barefoot walking and increase calf, leg and gluteal muscle activity. Manufacturers of the popular model Fitflop claim them to be flip-flops with a built-in-gym. The different flip-flops available on the market have been reviewed by American Podiatric Medical Association (APMA), which recommends only a few. According to APMA, the lack of support in a flip-flop can leave the wearer susceptible to sprained ankles and ligament injuries, and the limited protection offered to feet can mean a higher chance of cuts, scrapes, and stubbed toes. Penetrating injuries have previously been reported in rubber-soled shoes and flip-flops and they are therefore not recommended in diabetics, due to the lack of protection from injuries [48,49]. In general flip-flops appear to be suitable for normal feet but not for patients with foot pathology (Fig. 4).

12. APOS shoes

The APOS system was developed by APOS Medical and Sports Technologies Ltd., Israel and marketed in the UK in association with BUPA. The benefit supposedly comes from the design of the sole, which eliminates flat surface walking by using hemispherical, individually calibrated bio-mechanical units at the hindfoot and forefoot on the plantar surface. These units can be moved medially, laterally, forward, and backward, and may be individually adjusted in order to balance loads. In a double blind randomised controlled study of 61 knee osteoarthritis patients over 8 weeks, 70% reduction in pain and 33% improvement in function was observed and the benefits were maintained at 1 year follow up [50]. APOS shoes are

Fig. 5. APOS shoes (published with permission).

currently recommended for knee osteoarthritis, but not for any foot pathology (Fig. 5).

13. Conclusions

Based on our observations we feel that young children with flatfeet should be encouraged to walk barefoot to strengthen intrinsic muscles and develop arches instead of using arch support insoles. Currently there is not enough evidence to support either of these. There is scope for prospective studies comparing barefoot walking and use of insoles for flexible flatfeet in children.

The commercial orthopaedic footwear market appears to be flooded with shoes, but most of these do not have enough scientific and clinical evidence to support their use. Many of these claim to mimic barefoot walking and create an unstable gait. Unstable shoes may be useful in specific foot pathology. Shoes which decrease hindfoot loading (such as MBT) may be useful for hindfoot pathology. Shoes which decrease forefoot loading (such as earth shoes) may be useful for forefoot problems. Flip-flops should be avoided by diabetics as they do not protect from injuries. Patients often use these commercial footwear for non-specific foot problems without getting appropriate advice. This could even exacerbate their condition and symptoms. Patients should be encouraged to seek appropriate clinical opinion before using these footwear.

Conflict of interest

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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