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Effects of footwear on the knee adduction moment in medial knee osteoarthritis: classification criteria for flat flexible vs stable supportive shoes

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Objective: To validate simple criteria that distinguish flat flexible from stable supportive walking shoes by comparing their effects on the knee adduction moment (KAM) in people with medial knee osteoarthritis (OA).
Design: This was a cross-sectional biomechanical study. We proposed five criteria to differentiate flat flexible from stable supportive shoes, and selected three pairs of shoes representing each class for biomechanical testing. 28 participants aged ≥50 years with symptomatic medial knee OA underwent gait analysis barefoot and wearing each of the six selected shoes, in random order. Differences in the peak KAM, KAM impulse and peak knee flexion moment (KFM) across test conditions were evaluated with a two-way repeated measures analysis of variance (ANOVA). Immediate changes in walking pain between conditions were also compared.
Results: Increases in KAM from barefoot were lower with each of the three flat flexible shoe styles (peak KAM: 6.1–8.9%; KAM impulse: 2.4–5.1%) compared to their stable supportive counterparts (peak KAM: 11.6–15.1%; KAM impulse 10.5–13.2%). There was a significant main effect for footwear class on peak KAM and KAM impulse, whereby stable supportive shoes increased the KAM significantly more than flat flexible shoes ($P < 0.001$). There were no differences in the KFM or immediate walking pain between footwear classes.
Conclusions: Our proposed criteria can be used by researchers and clinicians to select flat flexible shoes for people with medial knee OA to minimise knee loading. Future research should evaluate whether wearing shoes based on these criteria translates to improvements in knee OA symptoms and/or slows structural disease progression.

Knee osteoarthritis (OA) is a global health problem that causes significant pain and disability, leading to reduced quality of life[1]. It has no cure, thus treatments that reduce symptoms and delay need for arthroplasty are critical. Clinical guidelines emphasize non-drug non-surgical strategies, and in particular, self-management is universally advocated[2–4]. For effective self-management, "appropriate" footwear is recommended yet there is little evidence to inform appropriate footwear choice for people with knee OA. As such, leading international bodies have identified footwear as a research priority for OA[2,4]. Older adults with joint pain have also prioritized research into lifestyle and self-management strategies over drugs and surgery[5], and a stakeholder panel recently identified biomechanical strategies as a high-priority evidence gap[6]. However, before clinical trials of footwear can be conducted, research is needed to identify shoe styles with favourable biomechanical features that have the most potential for reducing OA symptoms.

Abnormalities in joint loading are a major contributor to the pathogenesis of knee OA[7]. Cross-sectional research has reported that increases in parameters of the external knee adduction moment (KAM), a surrogate measure of medial to lateral knee load distribution[8], are associated with increased severity of pain and

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physical dysfunction in those with established knee OA[9,10], whilst prospective studies have shown a higher KAM is related to incident knee pain in older people[11], and increased risk of structural progression over time[9,12–15]. Foot position and motion are related to knee loads[16,17], and footwear has a major influence on these biomechanics. Given the repetitive nature of knee loading, over thousands of steps/day, it is vital people with knee OA wear shoes that minimize knee load.

Wearing shoes increases the KAM compared to barefoot walking[18,19], and some types of shoes increase knee load more than others[20]. As walking barefoot is not a safe or practical option for older people with knee OA, identifying shoes and shoe features that are associated with lower knee loads is important. The limited biomechanical research conducted in people with knee OA to date suggests that flat flexible shoes result in knee loads that more closely approximate barefoot walking than shoe styles that are more stable and supportive of the foot[20–22]. Unfortunately, it is the latter shoe styles that people with knee OA are currently advised, and choose, to wear[23]. In contrast to flat flexible shoes, stable supportive shoe styles support the medial longitudinal arch of the foot (sometimes called “stability” or “motion-control” shoes by manufacturers) and limit pronation to provide foot stability. Many conventional athletic/recreational shoes fall into this category as they typically have features to support the medial arch, and thus are considered stable and supportive. Currently, it is unclear whether characteristics such as medial arch support have favourable or adverse effects on the KAM in people with OA. While some studies have shown reductions in the KAM when using a combined lateral wedge/medial arch support[24,25], it appears that the reduction in KAM is largely driven by the lateral wedge orthotic[26,27]. In fact, findings suggest that the KAM is increased when a medial arch support is used in isolation[25,28,29]. However, recent additions to the market also include shoes with flat, thin, flexible soles which minimize interference with natural foot motion during walking. These shoe styles appear most promising for knee OA based on biomechanical data[20–22].

There is little research exploring the effects of flat flexible shoes on knee loads, relative to more stable supportive shoe styles, in people with knee OA. Clinical application of findings is also hampered by the absence of objective criteria that distinguish flat flexible shoe styles from others. Of the published studies evaluating common footwear in people with knee OA[20–22,30,31], it appears that shoes with a thin heel thickness, a lower heel pitch (difference in sole thickness between heel and forefoot), absence of arch support or motion control features, a flexible sole and lighter weight are associated with lower knee loads. The primary aim of this study was to compare the effects of a range of flat flexible shoes to a range of more stable supportive shoes on parameters of the KAM in people with symptomatic medial knee OA. A secondary aim was to examine the effects of both shoe classes on the knee flexion moment (KFM), as recent research suggests that this parameter may also be associated with medial tibiofemoral contact force[32]. By using pre-defined measurable criteria to distinguish flat flexible shoes from stable supportive shoes, we aimed to validate simple criteria that could be used to define these classes of shoe. We hypothesized that flat flexible shoes selected according to our predefined criteria would result in lower peak KAM, KAM impulse and KFM than stable supportive shoes.

Materials and methods

Participants

Twenty-eight community volunteers were recruited from those completing a clinical trial in our laboratory (from the control arm only)[33]. At the baseline visit for the clinical trial, participants were required to: (1) be aged ≥50 years, (2) report knee pain on most days of the previous month, (3) report a minimum average pain score of 4 in the past week on an 11-point numerical rating scale (NRS, with terminal descriptors of ‘no pain’ and ‘worst pain possible’), (4) have radiographic evidence of knee OA (defined as Kellgren & Lawrence (KL) grade ≥2[34]); and (5) have medial tibiofemoral compartment OA on X-ray (defined as ≥grade 1 medial osteophytes and ≥grade 1 medial joint space narrowing that is greater than lateral narrowing[35]). People were excluded if they (1) reported foot/ankle pain/pathology, (2) had predominant lateral tibiofemoral knee OA or other knee pathology likely to be causing knee pain, (3) had an intra-articular corticosteroid injection or knee surgery to either knee within the previous 3 months, or planned knee surgery in the subsequent 6 months; (4) had any other muscular, joint or neurological condition influencing lower limb function; (5) reported current or previous (last 6 months) use of a shoe insert, knee or ankle brace; (6) were unable to walk unaided; or (7) had a body mass index (BMI) ≥36 kg/m^2. For the present study, an additional eligibility criterion was a shoe size between US 8 and 11 (reflecting the range of study shoe sizes we had available). All protocols and procedures were approved by the local institutional review board and all participants provided informed consent.

Participant characteristics

Demographic information including gender, age and duration of symptoms was recorded upon exit of the clinical trial. Height and mass were measured and were used to calculate BMI. Participants rated their overall average pain on walking over the previous week using an 11-point NRS with terminal descriptors of ‘no pain’ and ‘worst pain possible’. We also evaluated self-reported knee OA symptoms using the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index[36]. The WOMAC is comprised of three subscales that assess pain (five items, score range 0–20), stiffness (two items, score range 0–8) and function (17 items, score range 0–68). Responses were recorded on a 5-point Likert scale and scores for each subscale were summed, with higher scores indicating worse symptoms[36].

Footwear conditions

We reviewed the literature for knee OA studies that compared flat flexible to stable supportive shoes[20–22,30,31]. From these studies, we *a priori* identified key characteristics that distinguished the two shoe classes. To enable the criteria to be applied relatively easily by clinicians, these characteristics were also required to be objectively measureable using methods readily available in the clinical setting. If the information was not provided in the publication (e.g., shoe weight), we endeavored to source it directly using information provided by the manufacturer online, or by direct measurement of a pair of the shoes in our laboratory.

The footwear data extracted were:

i. heel thickness; if not reported or available elsewhere, this was measured in our laboratory using digital calipers, from the inside of the heel centre within the shoe to the underside of the heel centre on the external outersole [Fig. 1(a)]. If the shoe had an insole/sockliner, heel thickness was measured with this in place;
ii. shoe pitch; if not reported or available elsewhere, this was measured in our laboratory as the difference between the thickness of the rearfoot and forefoot, where each was measured using the same technique as the heel height measurement [Fig. 1(b)];