Conservative biomechanical strategies for knee osteoarthritis

Neil D. Reeves and Frank L. Bowling

Abstract | Knee osteoarthritis (OA) is one of the most prevalent forms of this disease, with the medial compartment most commonly affected. The direction of external forces and limb orientation during walking results in an adduction moment that acts around the knee, and this parameter is regarded as a surrogate measure of medial knee compression. The knee adduction moment is intimately linked with the development and progression of knee OA and is, therefore, a target for conservative biomechanical intervention strategies, which are the focus of this Review. We examine the evidence for walking barefoot and the use of lateral wedge insoles and thin-soled, flexible shoes to reduce the knee adduction moment in patients with OA. We review strategies that directly affect the gait, such as walking with the foot externally rotated ('toe-out gait'), using a cane, lateral trunk sway and gait retraining. Valgus knee braces and muscle strengthening are also discussed for their effect upon reducing the knee adduction moment.

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Learning objectives

Upon completion of this activity, participants should be able to:

1 Specify maladaptive biomechanics associated with the development of knee osteoarthritis (OA).
2 Prescribe footwear effectively for patients with knee OA.
3 Analyze the efficacy of insoles for patients with knee OA.
4 Evaluate physical training to improve biomechanics in knee OA.

Introduction

Osteoarthritis (OA) is the most common joint disorder and estimated to affect just over 20 million adults in the USA.[1] Knee OA is one of the most prevalent forms of this degenerative joint disease[1–3] and is associated with pain, functional impairment and a high economic cost.[4,5]

The medial tibiofemoral compartment of the knee is most commonly affected by OA[6,7] and this predilection probably reflects the loading experienced during daily locomotor activities.

The integral role of biomechanical factors in the development and progression of OA, especially of the lower limb, is becoming widely acknowledged.[8–10] Throughout the entire stance phase of walking, an external adduction moment acts around the knee joint, which tends to rotate the tibia medially with respect to the femur in the frontal plane (Figure 1a).[11,12] This external knee adduction moment is primarily caused by a medially acting ground reaction force, which is present during level walking and other locomotor paradigms, such as stair negotiation (Figure 1a).[13–16] The magnitude of the knee adduction moment is influenced by the magnitude of the ground reaction force, the moment arm of the ground reaction force about the knee joint center (defined as the perpendicular distance between the action line of this force and the knee's center of rotation), and the mass and acceleration of lower limb segments (Figure 1a). A high knee adduction moment reflects increased compressive forces acting on the medial aspect of the knee and is widely regarded as a surrogate measure of medial knee compression.[17–20]

Varus knee alignment (Figure 1b) has been reported as one of the best predictors of a high knee adduction moment.[21] Studies in patients with OA have calculated the coefficient of correlation as 0.52,[22] 0.61[23] or 0.75[24] between varus knee alignment and the peak knee adduction moment during walking. In line with this association, patients with moderate-to-severe OA show an increased varus knee alignment of between 2° and 6° compared with patients with mild to moderate symptoms.[22,24–27] In patients with a high preoperative knee adduction moment (but not those with a low preoperative knee adduction

Competing interests
The authors, the journal Chief Editor J. Buckland and the CME questions author C. P. Vega declare no competing interests.

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Key points

- Knee osteoarthritis (OA) is closely associated with the development of a high external knee adduction moment, which reflects compression of the medial compartment of the knee
- The nature of biomechanical loading at the knee joint can be altered by a number of conservative intervention strategies, which are potentially capable of slowing the progression of the disease
- Using lateral wedge insoles or thin-soled, flexible shoes can reduce the knee adduction moment and thus contribute to retarding the progression of OA
- Strategies that directly modify gait characteristics, such as a toe-out gait, lateral trunk lean and the use of a walking stick, can reduce the knee adduction moment
- Intervention strategies that act either directly or indirectly upon the knee joint, such as valgus knee braces and muscle strengthening, can effectively decrease the knee adduction moment

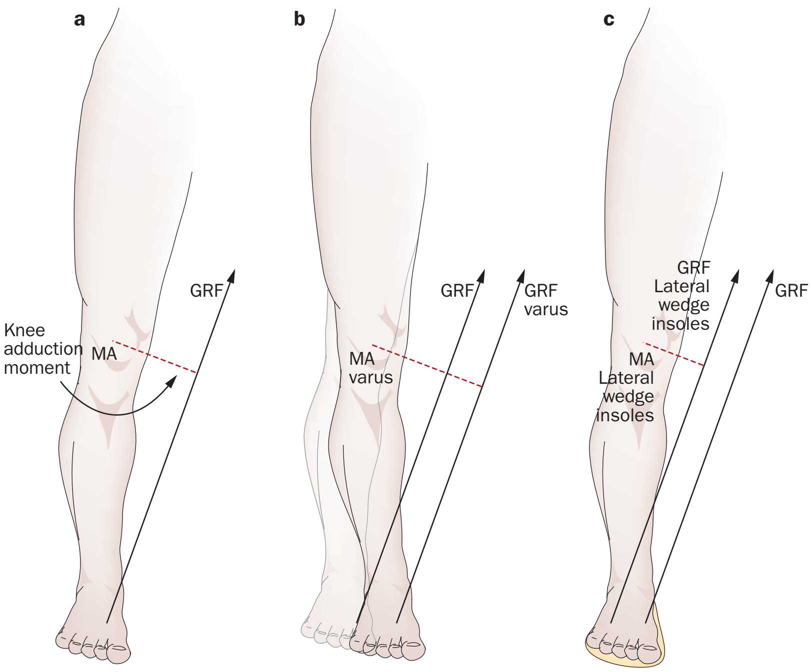

Figure 1 | The external knee adduction moment during walking. The magnitude and direction of the GRF are shown by the height and direction, respectively, of the straight arrows. The length of the MA of the GRF acting about the knee joint is indicated by dotted red lines. **a** | The knee adduction moment increases if the length of the MA increases, or the GRF magnitude increases, or both. **b** | A varus knee deformity (dark-shaded leg) is superimposed over a neutrally aligned knee (light-shaded leg). In the varus-aligned knee, the center of pressure (indicated by the origin of the GRF vectors) has shifted in the medial direction, increasing the MA of the GRF and, therefore, the knee adduction moment. **c** | Lateral wedge insoles shift the center of pressure, causing the GRF to pass closer to the knee joint center (assuming the GRF angle remains constant). This effect decreases the MA of the GRF about the knee and reduces the knee adduction moment compared with the situation without lateral wedge insoles. Abbreviations: GRF, ground reaction force; MA, moment arm.

moment), the re-emergence of a varus deformity ~5 years after proximal tibial osteotomy to achieve a valgus correction[28] underlines the central role of high knee adduction moments in both the development and progression of knee OA. Indeed, a high knee adduction moment is a very strong predictor of OA progression.[18]

The evidence unequivocally suggests that high knee adduction moments are intimately linked with the severity of medial knee OA, although a causal relationship might be difficult to establish. Patients with medial knee OA demonstrate considerably higher knee adduction moments during walking compared with matched controls.[26,29–32] The magnitude of the knee adduction moment discriminates most strongly between patients with moderate-to-severe OA and controls, whereas patients with mild OA demonstrate slightly less marked differences in knee adduction moment compared with controls.[26,27,32] Patients with severe knee OA, identified on the basis of radiographic disease severity (Kellgren–Lawrence grades 3–4) display higher knee adduction moments than do those with mild OA (Kellgren–Lawrence grades 1–2).[22,25,33]

Although the majority of studies have focused upon the peaks in the knee adduction moment profile during walking (Figure 2), the patients most severely affected by knee OA might show less identifiable peaks than do individuals with mild-to-moderate symptoms and healthy controls.[34] Instead, patients with the most severe symptoms show a 'flattened' knee adduction moment profile, indicating that the knee adduction moment does not decrease mid-stance, unlike in those with mild symptoms and healthy controls. The knee adduction angular impulse (defined as the integral of the knee adduction moment-time curve) can be used to discriminate between patients with knee OA of varying severity when no differences are apparent in the peak knee adduction moments.[32] Even if there are no differences in the two peaks between patients with severe OA and patients with mild or moderate OA, those with severe OA do not show a clear 'dip' between the two peaks and hence, will have a larger area under the knee adduction moment-time curve.[34]

In this Review, we discuss the published data on conservative biomechanical intervention strategies aimed at reducing the knee adduction moment and thereby preventing or slowing the progression of medial knee OA. This article is considered particularly timely given the current high prevalence of OA and its considerable social and economic effects.[1–5] This Review will, therefore, serve as a useful guide for medical and health-care practitioners who need to evaluate treatment options for patients with this disease.

Footwear interventions

Wearing inappropriate footwear could be intimately linked with the development and progression of medial knee OA, especially considering that the prevalence of knee OA and total knee replacement surgery is much higher in women than in men.[2,35] In healthy women, high-heeled shoes increase the knee adduction moment by 18–23% and reduce the ankle eversion moment by 75% compared with barefoot walking (Table 1).[36,37] These changes are probably related to a medial shift in the center of pressure, which increases the adduction moment arm at the knee (assuming the angle of the ground reaction force vector with the ground remains constant). The use of appropriate shoes can help to reduce the knee adduction moment and potentially delay the onset and progression of knee OA (as discussed in the sections below). Appropriate footwear can be easily incorporated into an individual's daily routine; however, longitudinal studies are required to confirm the long-term efficacy of this approach.

Barefoot walking

Walking barefoot reduces peak knee adduction moments in patients with medial knee OA by 7–13% compared with walking in normal shoes or in thick-soled shoes that offer stability and support (Table 1).[38,39] Some researchers have attributed the reduced knee adduction moments reported while walking barefoot to decreased walking speed,[40] since slow walking speeds also result in reduced peak knee adduction moments.[26,41,42] However, other teams have reported that the benefit of walking barefoot was still present when walking speeds remained constant between shod and barefoot conditions,[38,39,43,44] indicating that a slow walking speed alone is unlikely to be the underlying mechanism.

Although barefoot walking could reduce the knee adduction moment, thereby potentially influencing the progression of OA, it is clearly not a very practical strategy to adopt in daily life. The implications are, however, that shoes that mimic the barefoot movement might be a more clinically relevant alternative. Indeed, a custom-engineered 'mobility shoe', designed to promote foot flexibility and mimic the essential aspects of barefoot walking, lowered the peak knee adduction moment and the angular impulse in patients with knee OA to a similar extent to barefoot walking (~12%).[44]

Flexible shoes versus stability shoes

Interestingly, peak knee adduction moments while walking barefoot were similar to those measured in patients wearing flat walking shoes and 'flip-flops' (Table 1).[39] These two types of footwear have thinner and more flexible soles than the thick-soled, supportive, 'stability shoes' used in other studies (Table 1).[44] Such footwear might enable increased foot flexibility in a manner similar to that of barefoot walking.

Thin-soled, flexible shoes seem to be beneficial for reducing knee joint loads compared with shoes with thicker soles (Table 1). Despite appearing counter-intuitive, shoes with thick soles actually seem to increase joint loading at the medial tibiofemoral compartment, whereas shoes with thin soles are associated with reduced knee adduction loading.[39] Although thick-soled shoes might cushion direct loading on the plantar surface of the foot, they seem to mask the transfer of loads further up the kinetic chain. When walking barefoot or in comparatively thin-soled shoes, the plantar surface of the foot is relatively sensitive to impact loading and gait might, therefore, alter so as to elicit reduced ground reaction forces.[39,43,44] Indeed, these differences in impact loading could relate to the kinematic alterations observed to occur in barefoot walking, namely shorter stride lengths[38,39,43,44] and smaller ranges of motion in the knee

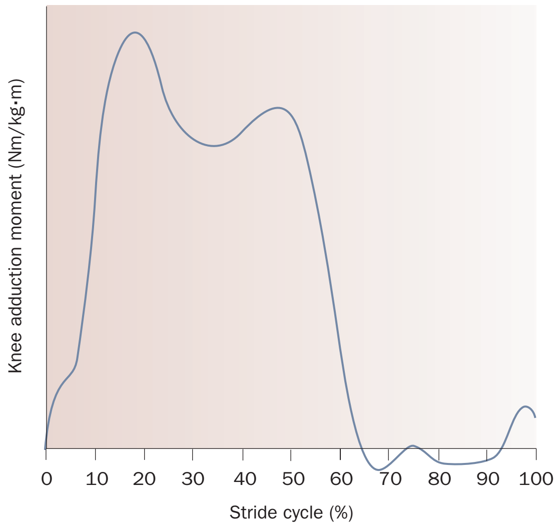

Figure 2 | Schematic representation of the knee adduction moment profile during walking showing the characteristic double peak associated with the stance phase. The stride cycle begins at the initial foot contact (0%) through to the subsequent contact of the same foot with the ground (100%).

and ankle joints compared with walking in thick-soled shoes.[38,39,44] Such kinematic differences reflect reduced knee extension and dorsiflexion upon ground contact, indicating a reduced heel strike and an increased tendency to a mid-foot landing that might translate to a 'softer' ground impact compared with the situation while walking in shoes. This softened impact would particularly contribute to reducing the first (and largest) peak of the knee adduction moment profile (Figure 2). Thus, wearing shoes that have a thin and flexible sole, and little or no heel, offers a potentially useful strategy for effectively modifying the biomechanical factors influencing progression of OA.

Lateral wedge insoles

Lateral wedge insoles (that is, a wedge inclined along the outside of the foot) have been suggested as an intervention strategy to reduce the knee adduction moment during walking and attenuate the progression of medial knee OA.[45,46] In patients with OA, the use of lateral wedge insoles of between 5° and 15° inclination reduced peak knee adduction moments by between 4% and 14% during walking compared with the corresponding values either without insoles or wearing even-thickness control insoles (Table 2).[47–51] The use of lateral wedge insoles also led to immediate reductions in pain during walking.[48] Extension of the lateral wedge along the entire length of the foot is an important factor, as the knee adduction moment was only reduced with a full-length insole, not with a lateral wedge covering just the heel region.[47] Lateral wedging of just the heel could be a factor in studies that have failed to demonstrate any influence of lateral wedge insoles on the knee adduction moment in patients with OA.[52] Individualized prescription of the degree of inclination for the lateral wedge insole might minimize the discomfort previously reported with use

Table 1 | Immediate influence of barefoot walking and various types of footwear on the knee adduction moment

Study	Knee adduction moment reduction (%)		Comparator condition	Further footwear details
	(1st peak)	(2nd peak)		
Barefoot walking				
Shakoor & Block (2006)[38]	12	NR	Participant's own shoes	NR
Shakoor *et al.* (2010)[39]	13	NR	Clogs typically worn by health professionals	Heel height 50 mm
Shakoor *et al.* (2010)[39]	10	NR	Stability shoes	Flexible forefoot area, rigid heel area; heel height 50 mm men, 40 mm women
Shakoor *et al.* (2010)[39]	4	NR	Flat walking shoes	Flexible shoe allowing foot mobility; heel height 10–15 mm
Shakoor *et al.* (2010)[39]	No difference	NR	Flip-flops	Flexible rubber, heel height 15 mm
Shakoor *et al.* (2008)[44]	13	NR	Stability shoes	Substantial rearfoot stability
Kemp *et al.* (2008)[43]	7	NR	Participant's own shoes	Shoes typically used for walking
Kerrigan *et al.* (1998)[37]	19	19	Women's high-heeled (narrow) shoes	6 cm high-heeled shoes, narrow base
Kerrigan *et al.* (2001)[36]	18	23	Women's high-heeled (wide) shoes	7 cm high-heeled shoes, wide base
Mobility shoes				
Shakoor *et al.* (2008)[44]	2	NR	Barefoot walking	Flexible, light-weight mobility shoe

Abbreviation: NR, not reported.

Table 2 | Immediate effects of lateral wedge insoles on the knee adduction moment in patients with osteoarthritis

Study	Lateral wedge inclination (°)	Knee adduction moment reduction (%)			Comparator condition
		1st peak	2nd peak	Stance phase mean	
Hinman *et al.* (2008)[48]	5	5	9	NR	No insole
Kerrigan *et al.* (2002)[51]	5	4	4	NR	3.2 mm even-thickness control insole
Kerrigan *et al.* (2002)[51]	5	5	6	NR	No insole
Kakihana *et al.* (2005)[49]	6	NR	NR	6	Even-thickness control insole
Kerrigan *et al.* (2002)[51]	10	8	7	NR	6.4 mm even-thickness control insole
Kerrigan *et al.* (2002)[51]	10	8	8	NR	No insole
Butler *et al.* (2009)[50]	5°–15° (mean 10°)*	9	NR	NR	Even-thickness control insole
Hinman *et al.* (2008)[47]	5 (full-length insole)	12	14	NR	No insole

*Individualized prescription. Abbreviation: NR, not reported.

of large wedges[51] and optimize reductions in the knee adduction moment.[50]

Lateral wedge insoles reduce knee adduction moments in patients with early to mild OA (Kellgren–Lawrence grades 1–2), but not in patients with moderate-to-severe OA (Kellgren–Lawrence grades 3–4).[53] Consistent with previous reports, such insoles were ineffective in patients with the most advanced stages of OA.[45] This lack of efficacy has been attributed to the increased severity of varus deformity (Figure 1b) in patients with advanced OA (Kellgren–Lawrence grades 3–4) compared with those with mild OA (Kellgren–Lawrence grades 1–2).[53] Other intervention strategies might need to be considered for individuals most severely affected by the disease.

Mechanism of effect

The predominant mechanism responsible for the decrease in the knee adduction moment observed with lateral wedge insoles is a lateral shift in the center of pressure,[20,49,54] which has the effect of reducing the moment arm of the ground reaction force around the knee in the frontal plane (Figure 1c). This lateral shift in the center of pressure also means that the ankle eversion moment increases,[49] potentially by up to 93%.[50] This increase could have implications for patients with OA who have acute ankle sprains or chronic ankle instability.[55] Another potential problem is that the use of lateral wedge insoles has been reported to increase step width during walking in healthy individuals[56] and patients with

OA.[53] An increased step width increases medially directed ground reaction forces and, if all other factors remain constant, elevates the knee adduction moment. Lateral wedge insoles could, therefore, reduce the knee adduction moment even further if an increased step width can be avoided. The addition of a medial arch support to lateral wedge insoles seems to normalize step width.[56] Caution should be emphasized, however, as the use of a medial arch support alone (as frequently prescribed by health professionals) actually increases the knee adduction moment slightly[57] and thus could exacerbate knee OA. The decrease in knee adduction moment observed with the use of lateral wedge insoles is sustained even after 1 month of continual wear in patients with OA.[58] Perhaps as expected, the decrease in knee adduction moment only occurs while the patients are actually wearing the insoles.[58]

Long-term benefits

After a 3-month[48] and 12-month[59] intervention with lateral wedge insoles, patients with OA experienced reductions in pain and improvements in physical function. A 2-year, randomized, controlled study failed to show any symptomatic or structural benefits of lateral wedge insoles over control insoles in patients with medial knee OA.[60] This contrasting result could be (at least partly) explained by the use of lateral wedge insoles that only covered the heel region rather than the entire lateral border of the foot.[47] Although this study failed to show any difference in pain reduction between the groups, patients using lateral wedge insoles had a substantially lower intake of anti-inflammatory medication.[60] A 2-year intervention in patients with OA showed that although lateral wedge insoles alone were unable to cause any alterations in pain and varus deformity, when combined with subtalar strapping these insoles reduced pain and improved tibiofemoral joint alignment.[61]

Whereas the long-term benefits of lateral wedge insoles do not seem conclusive, their immediate effect on the knee adduction moment is readily apparent. In terms of clinical utility, this intervention can be easily incorporated within a patient's daily routine. Considering their immediate positive influence on the knee adduction moment and clinical utility, lateral wedge insoles should be considered as a potentially useful intervention, especially for patients with early OA.

Variable-stiffness shoes

'Variable-stiffness' shoes with increased lateral stiffness have been tested as an alternative to lateral wedge insoles. Variable-stiffness shoes considerably reduced the peak knee adduction moment during walking (by up to 6%) in patients with OA compared with constant-stiffness control shoes.[62] Peak knee adduction moments were reduced to a greater extent by the variable-stiffness shoes at fast (6% reduction) compared with slow (2% reduction) walking speeds, indicating increased shoe compression and, therefore, improved effectiveness at fast walking speeds.[62] Variable-stiffness shoes should, therefore, be considered a potentially useful intervention for patients with early OA.

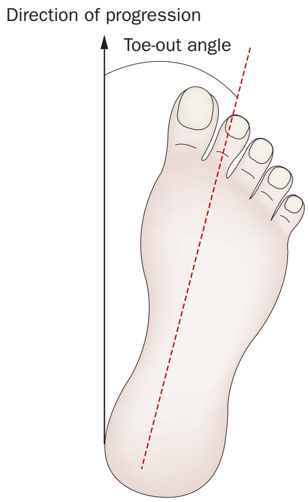

Figure 3 | Schematic diagram illustrating the 'toe-out' gait. The toe-out angle is defined as the degree of external rotation of the foot with respect to the direction of progression.

Gait modification approaches

Toe-out gait

Walking with a toe-out gait—that is, with the foot externally rotated with respect to the direction of progression (Figure 3)—reduces the knee adduction moment in patients with medial knee OA.[63–65] The mechanism underlying this reduction seems to be different for each of the two peaks in the knee adduction moment (Figure 2). A toe-out gait causes a shift in the knee joint axis (that is, an externally rotated knee) that results in a portion of the external knee adduction moment being converted to an external knee flexion moment. This change contributes particularly to reducing the first of the two peaks in the knee adduction moment.[64] This shift in the knee joint axis causes the ground reaction force to pass more posterior (increasing the external knee flexion moment) and less medial (reducing the external knee adduction moment) to the externally rotated knee. By contrast, the reduction in the second peak of the knee adduction moment observed with a toe-out gait occurs mainly because of a decreased moment arm, caused by a lateral shift in the path of the center of pressure.[64] This shift occurs in late stance as the center of pressure moves towards the toes, and causes the ground reaction force to pass closer to the knee joint center, presumably without changing the angle of the ground reaction force vector with the ground (Figure 1).[64] This mechanism of the toe-out gait seems to be specific to the second peak of the knee adduction moment, as the center of pressure travels further towards the toes to generate the second peak when the foot is externally rotated (Figure 3). By contrast, the center of pressure is located closer to the heel (that is, positioned more medially) during the first peak of the knee adduction moment and would, therefore, be far less affected than the second peak by a toe-out gait (Figure 2).

Studies have reported a reduction in the second (but not the first) peak of the knee adduction moment in patients with OA when the foot is externally rotated by between 10° and 21° beyond the natural foot position during walking.[63,65] Indeed, an inverse correlation between the magnitude of the second peak knee adduction moment and the toe-out angle has been consistently reported in both patients with OA[24,66] and healthy participants.[67,68] The lack of consensus regarding the reductions in the first peak of the knee adduction moment achieved with a toe-out gait could relate to the fact that this foot position can result from external rotation at either the ankle or hip. The mechanism to reduce the first peak knee adduction moment (detailed above)[64] requires external rotation of the knee joint axis, which can only be achieved via external rotation at the hip.

With respect to the long-term influence of toe-out gait, an increased baseline toe-out angle was associated with a reduced likelihood of disease progression in patients with medial knee OA over an 18-month follow-up period.[66] Although data relating to the long-term effects of toe-out gait are scarce, its immediate effect is to consistently reduce the second peak of the knee adduction moment, with less consistent effects upon the first peak of this parameter (Figure 2). Despite this strategy being relatively simple and not requiring any equipment, it does require permanent adoption of an altered gait by the patient. Nevertheless, if patients can adhere to this strategy, it offers potential for reducing the progression of knee OA.

Lateral trunk lean

In individuals who lean towards the side of the weight-bearing limb as they walk, the body's center of mass shifts laterally and moves closer to the center of pressure under the weight-bearing foot. As the ground reaction force tends to act through the center of mass, this approach changes the angle of the ground reaction force, shifting it towards the knee joint center. The outcome of this shift is a reduction in the moment arm of the ground reaction force that, in turn, reduces the knee adduction moment (Figure 1). Lateral trunk lean has, therefore, been suggested as a compensatory strategy to reduce the knee adduction moment in patients with OA.[23,26,69]

The extent of lateral trunk lean is inversely correlated with the magnitude of the knee adduction moment in individuals with OA.[23] As a compensatory strategy to unload the affected knee, greater degrees of lateral trunk lean have been reported in patients severely affected by the disease compared with those experiencing mild symptoms.[70] In healthy participants, walking with an exaggerated lateral trunk sway reduced the knee adduction moment by 65% compared with normal walking.[71] Although this compensatory strategy could be effective for reducing the knee adduction moment, it should be treated with caution when considered as an 'imposed' intervention in patients owing to the risk of falling associated with excessive upper body sway.

Gait retraining

Gait modification approaches have been advocated to reduce the knee adduction moment and delay the progression of knee joint OA.[72–74] For example, the medial thrust gait pattern involves consciously pushing the knee joint in a medial direction during walking, which repositions the knee joint center closer to the ground reaction force, thus reducing the moment arm and lowering the knee adduction moment (Figure 1). In case studies of individuals with OA who have adopted this strategy, the knee adduction moment[73] and medial tibial contact forces[72] were markedly reduced.

Walking aids

In patients with OA, the use of a cane or walking stick in the hand contralateral to the symptomatic knee reduced the peak knee adduction moment by 10%.[43] Patients must, however, be careful not to use their cane in the hand on the same side as the symptomatic leg, as this technique can actually increase the knee adduction moment.[75] Using a cane in the hand contralateral to the symptomatic knee might shift the body's center of mass towards the affected limb, thereby reducing the medially directed ground reaction force, in a similar way as that achieved with the lateral trunk lean strategy described above.

Cane use, in conjunction with a slow walking speed, lowered the ground reaction force,[43] and decreased the biomechanical load experienced by the lower limb. The use of a cane and walking slowly could, therefore, be simple and effective intervention strategies for patients with OA. In a similar manner to which cane use unloads the limb, weight loss also decreases load in the limb to a certain extent and should be considered as a long-term strategy, especially for overweight individuals.

Valgus knee braces

Valgus knee braces secured around the thigh and lower leg and worn throughout the day have been suggested as a conservative treatment strategy for patients with medial knee OA (Figure 4). The underlying rationale for use of a valgus knee brace is the application of a valgus moment (knee abduction moment) to the knee joint (Figure 4), which could reduce the knee adduction moment during walking and unload the medial compartment of the knee.[12,17,19,76,77] Although reports of this approach have been mostly positive, studies of valgus knee braces in patients with OA have not conclusively demonstrated an improvement in the external knee adduction moment. The external knee adduction moment either decreased,[12,77] showed a tendency to decrease,[76] or did not change[19,78] when a valgus brace was used compared with an unbraced condition. However, these results refer to the external knee adduction moment only. The valgus brace itself exerts a moment that opposes the external knee adduction moment (Figure 4).[12,19,79] This factor should be considered when evaluating the brace's effectiveness in unloading the medial knee compartment. The net knee adduction moment in a patient wearing a valgus brace is calculated as the external knee adduction moment minus the valgus moment exerted by the knee brace.

Valgus knee braces reduce the net knee adduction moment during walking in healthy young adults[79] and in patients with medial knee OA.[19] Considering, therefore, that valgus knee bracing predominantly affects the net knee adduction moment, studies indicating that the external knee adduction moment decreases with bracing[12,76,77] suggest that this approach has additional benefits for unloading the medial compartment of the knee. The decrease in the external knee adduction moment observed in individuals wearing a valgus knee brace could be related to a medial shift in the knee joint center leading to a reduction in the knee adduction moment arm (Figure 1).

Knee braces can be adjusted to increase the extent of valgus alignment, which also increases the valgus moment applied at the knee joint (Figure 4). The peak net knee adduction moment progressively decreased with increasing valgus alignment of the knee brace.[19] A neutrally aligned knee brace reduced the peak net knee adduction moment by 6% compared with the unbraced situation, whereas valgus brace alignments of 4° and 8° yielded reductions of 13% and 19%, respectively. These reductions in net knee adduction moment were estimated to give rise to decreases of between 8% and 17% in medial knee compartment loading during walking.[19] Estimations derived from a musculoskeletal model suggest that for every 1 Nm increase in the valgus brace moment, the net knee adduction moment decreases by 3% and the medial compartment load decreases by 1%.[20] These estimates are in agreement with fluoroscopic imaging data from a study of patients with medial knee OA.[17] 80% of these patients experienced a 2 mm increase in medial tibiofemoral joint separation while walking with a valgus knee brace compared with the unbraced control situation.[17] However, the 20% of patients who were obese did not derive any benefit from valgus knee bracing.[17] Although obese patients experience high joint loads that could partially explain their impaired response to bracing, the researchers ascribed this observation to problems with adequate fixation of the knee brace.[17] Excessive amounts of soft tissue seem likely to reduce the effective transmission of forces from the knee brace to the femur and tibia.

Pain is a cardinal symptom of knee joint OA, and a valgus knee brace substantially reduced pain for these patients immediately upon use,[17,80] and after continuous wear for durations ranging between 2 weeks and 12 months.[19,76,78,81,82] Improvements in function have also been reported in patients with OA following valgus knee bracing for durations of between 6 months and 12 months.[81,82] Although valgus bracing achieves effective unloading of the medial compartment of the knee and offers potential for improving the clinical outcome in patients with knee OA, the success of this intervention relies upon the patient being prepared to wear the knee brace continually. Valgus knee braces are bulky, potentially uncomfortable and might not be a practical daily solution for many patients.

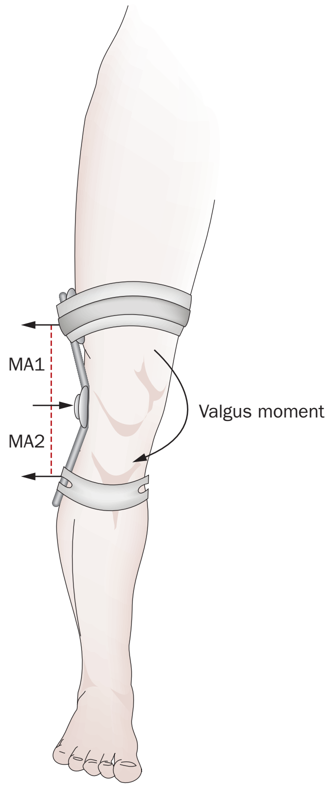

Figure 4 | Schematic diagram illustrating how valgus bracing counteracts the external adduction moment acting about the knee during walking. The brace applies points of force at three locations (indicated by arrows), which create MA1 and MA2, and result in a valgus moment about the knee. The red dotted line indicates the length of the two separate moment arms: MA1 and MA2 (distance from outer arrow to center arrow). Abbreviation: MA, moment arm.

Muscle strengthening

During walking patients with medial knee OA demonstrate elevated and prolonged activity of the lateral hamstring muscles as measured with electromyography compared with their medial hamstrings and both medial and lateral hamstrings of matched controls.[65,83–85] The lateral hamstring muscles can produce an internal valgus moment that counteracts the external knee adduction moment. The altered activity of the lateral hamstring muscles observed in patients with OA is probably an attempt to unload the medial knee compartment and counteract the high external knee adduction moments that they experience. The lateral hamstring muscles also have an important role in producing a toe-out gait,[65,85] which (as described above) can lead to reductions in the knee adduction moment.

Hip abductor training might exert an effect by stabilizing the frontal plane motion of the pelvis and trunk and via the development of an internal valgus moment at the knee. Results from a pilot study showed that 4 weeks of strength training involving the hip abductor muscles (such as the tensor fasciae latae muscle, which spans both the hip and knee joints) can decrease the external knee adduction moment by 9% and greatly reduce pain.[86] Although this study provided some encouraging results for this type of muscle strengthening, it lacked a control group and included only six patients.[86] A randomized, controlled trial with a much larger sample size (89 participants, of which 76 completed the trial, were randomly allocated to either hip strengthening or the control group) failed to show any effect of hip abductor and adductor muscle strengthening on the knee adduction moment, although it was effective for reducing pain.[87] Taking into account the rationale for medial compartment unloading, the lateral hamstrings and hip abductor muscles of patients with OA should be considered appropriate targets for muscle strengthening programs, although further studies are required to confirm the efficacy of this approach.

Quadriceps muscle strength training has conventionally been advocated for the treatment and/or management of OA;[88,89] however, no clear rationale exists as to how strengthening this specific muscle group would help to unload the medial compartment of the knee. Indeed, a 12-week quadriceps strengthening program in patients with OA failed to influence the external knee adduction moment and only relieved pain in patients with a fairly neutral knee alignment.[90] The intervention had no effect on pain in patients with a valgus knee alignment.[90]

Conclusions

The knee adduction moment has an integral role in the development and progression of knee OA. A number of conservative biomechanics-based interventions can reduce the knee adduction moment effectively via different mechanisms. Lateral wedge insoles can cause some discomfort and are effective primarily for patients with early stage OA. Walking with a toe-out gait consistently reduces the second peak of the knee adduction moment, but does not affect the first peak with the same consistency across studies. Walking barefoot or in thin-soled, flexible shoes reduces the knee adduction moment compared with wearing thick-soled, inflexible shoes. Knee braces that produce a valgus moment about the knee markedly reduce the net knee adduction moment and unload the medial compartment of the knee, but could be impractical for many patients. The lateral hamstring muscles and hip abductor muscles can produce an internal abduction moment that opposes the external adduction moment around the knee and should be targets for muscle strengthening programs. Use of a cane or walking stick in the hand contralateral to the symptomatic knee, lateral trunk sway and gait retraining are also effective strategies for reducing the knee adduction moment. Many of these conservative biomechanical strategies could be employed in early stage OA and might help to prevent and/or delay disease progression.

Review criteria

PubMed and MEDLINE databases were searched for articles focusing on knee adduction moments or knee joint loading in patients with osteoarthritis, using the term "knee osteoarthritis" in combination with "knee adduction moment", "biomechanics", "conservative intervention", "intervention strategies", "nonsurgical treatment", "management", "walking", "insoles", "lateral wedge insoles", "knee brace", "valgus knee brace", "toe-out gait", "barefoot walking", "shod", "footwear", "muscle", "quadriceps", "hamstrings", "muscle strengthening", "strength training" and "resistance training". Only articles written in English were selected.

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