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Introduction

The external knee adduction moment during gait is a clinically useful measure for studying the initiation and progression of medial compartment knee osteoarthritis (OA) [1]. This quantity is the frontal plane moment of the ground reaction force vector about the knee center and possesses two peaks during stance phase—a first during early stance and a second during late stance. The largest peak is highly correlated with medial contact force [43], disease progression [26], disease severity [33], and pain [38]. For this reason, the peak knee adduction moment has become a quantitative target for clinical treatment of medial compartment knee OA.

Gait modification has recently received attention as a noninvasive alternative to high tibial osteotomy. This article reviews the current status and future direction of gait modification as a treatment for medial compartment knee OA, covering what exists, what is missing, and what is next. The interested reader is also referred to recent review articles on related topics [3, 10, 16, 29, 35, 36].

Existing Approaches to Gait Modification

Methods for gait modification can be learned, meaning the patient learns to walk differently, or assisted, meaning an assistive object is used. Learned modifications that reduce the peak knee adduction moment include walking with decreased speed [28, 30], increased stance width [13], toes pointed outward [1, 15, 19], knees medialized [2, 14, 41], and increased medial–lateral trunk sway [17, 27]. Assisted gait modifications that reduce this moment include use of lateral wedge insoles [4, 20], lateral wedge insoles with subtalar strapping [22], variable stiffness shoes with softer medial side [9], high mobility shoes that mimic the natural flexibility of the foot [32], valgus knee braces that use three-point bending [7, 25], canes [21], and bilateral hiking poles to counteract the adduction moment of the opposite knee [12].

The reductions in peak knee adduction moment achieved by learned and assisted gait modifications are reported in Table 1. For learned modifications (Table 1, top), only walking with knees medialized or with a medial–lateral trunk sway produced reductions on the order of those achieved by high tibial osteotomy. Similarly, for assisted modifications (Table 1, middle), the most effective methods are use of variable stiffness shoes, lateral wedge insoles with the addition of subtalar strapping, or bilateral hiking poles. The ultimate goal of reducing the peak knee adduction moment is to reduce peak medial contact force during stance. For medial contact force changes measured during gait using instrumented tibial prostheses (Table 1, bottom), variable stiffness shoes and valgus knee braces have produced the largest reductions.

Several important caveats (indicated by stars in Table 1) exist for the medial contact force changes measured with instrumented implants. Walking with knees medialized and with hiking poles reduced the first peak only slightly but reduced the entire curve significantly over the rest of the stance [41]. Furthermore, elimination of excessive knee flexion during midstance may make these two methods effective at reducing the first peak as well [41]. The peak medial contact force reduction of 23% achieved by valgus knee braces should be viewed in light of the significant discomfort experienced by the subjects for this brace setting.

Current Challenges for Gait Modification

For learned gait modifications, a major challenge is how to get people to achieve them. Verbal instructions alone are insufficient for most patients. A related challenge is to understand why some patients cannot achieve a specified gait modification while others can. Most of the learned gait

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Table 1 Summary of changes in peak knee adduction moment due to learned (top section) and assisted (middle section) gait modifications and in medial contact force due to learned and assisted (bottom section) gait modifications. The reduction achievable by high tibial osteotomy is listed for comparison

Learned peak knee adduction moment reductions

Method	Reduction
High tibial osteotomy surgery	50% [40]
Decreased speed	8% [30]
Increased stance width	9% [13]
Toes pointed outward	38% [15] (second peak only)
Knees medialized	19% [2], 32% [41], 39% to 50% [14]
Increased trunk sway	20% [17], 65% [27]

Assisted peak knee adduction moment reductions

Method	Reduction
High tibial osteotomy surgery	50% [40]
High mobility shoe	8% [32]
Lateral wedge insole	9% [4]
Valgus knee brace	6% [7], 10% [25]
Cane	10% [21]
Variable stiffness shoe	6% [9], 13% [8]
Insole plus subtalar strapping	13% [22]
Bilateral hiking poles	33% [41]

Learned and assisted medial contact force reductions

Method	Reduction
Lateral wedge insole	1% to 4% [23]
Knees medialized	5% [41]*
Bilateral hiking poles	5% [41]*
Variable stiffness shoe	12% [8]
Valgus knee brace	7% to 23% [24]*

* Indicates important caveat discussed in the text

modification studies have used young healthy subjects; older subjects with knee OA and pathological gait mechanics pose a much greater challenge. Even if patients can achieve a gait modification, it is unclear whether they can retain it. Since athletes and musicians can learn and retain changes in movement patterns, at least some patients should be able to do the same.

For assisted gait modifications, a major challenge is how to make them more effective. Many of the assisted methods have produced only small changes in the peak knee adduction moment or peak medial contact force, and it is unclear whether such small reductions will be clinically meaningful. An additional challenge is how to get patients to use an assisted gait modification consistently. From a patient's perspective, the decrease in knee pain produced by an assistive device may not be large enough to outweigh the increase in discomfort.

Several important cautions exist for gait modification. First, a decrease in peak knee adduction moment does not guarantee a decrease in peak medial contact force. Walking with knees medialized or with hiking poles reduced the peak adduction moment (Table 1, top and middle) but produced little change in peak medial contact force (Table 1, bottom). Thus, the clinical situation appears to be more complex than indicated by the peak knee adduction moment alone. Second, beneficial changes at the knee could also induce detrimental changes at other joints [39]. Such changes are most likely to occur at the ankle or lower back, where load changes are often the largest. Third, different calculation methods yield different interpretations of the effectiveness of a given modification [31]. Many studies do not provide details of how the adduction moment was calculated, making it difficult to compare results. Furthermore, the angular impulse (the area under the knee adduction moment curve during stance) may be a better clinical target [5, 37, 38].

Future Directions for Gait Modification

One of the first efforts in the future should be reevaluation of the peak knee adduction moment as a clinical target. What is the "right" way (if one exists) to calculate this moment? It would be helpful if researchers reported sufficient methodological details for others to understand the coordinate system used for calculating the moment. It would also be valuable for large clinical studies to share deidentified gait data with the research community. Then other labs could investigate different calculation methods to determine how they correlate with reported clinical outcomes. Having multiple labs explore the same large data sets may lead to the discovery of another target (e.g., angular impulse or a combination of the adduction and flexion moments) that is a better surrogate for clinical outcome. While medial contact force may intuitively seem like the best mechanical target, this quantity cannot yet be calculated reliably using computer models.

A related question is how the target should change when a patient's gait pattern is modified. A quantity that predicts long-term clinical outcome well when a patient does not change his gait pattern may not be the right target when a patient changes his gait pattern. Longitudinal studies involving gait modification will be needed to address this issue.

Regardless of the target choice, a critical question is how to get patients to learn coordinated gait motions that can "hit" the target. Knowing the desired kinematic changes is only half the battle. The other half is figuring out how to get patients to achieve and retain them.

To this end, several recent studies have explored the use of real-time feedback to reduce the peak knee adduction moment during gait retraining. Reductions ranging from 7% to 48% were reported with real-time visual feedback of the knee adduction angle [2], vibratory feedback of ground contact force at the lateral edge of the foot [6], visual feedback of trunk lean angle [18], vibratory feedback of multiple kinematic parameters [34], and visual or vibratory feedback of the peak knee adduction moment calculated in real time, which allowed subjects to perform a "self-optimization" process [42].

Identification of the correct target is critical for studies that employ real-time feedback. If the selected kinematic feedback quantity is not an accurate surrogate for peak knee adduction moment, then subjects may learn to "hit" the desired target and yet not achieve significant moment reductions (e.g., [11]). Ideally the feedback quantity should be as close as possible to the quantity responsible for degenerative joint changes, though this quantity has yet to be determined definitively.

Summary

By changing pathological joint mechanics, gait modification may have disease modifying potential for medial compartment knee OA. The most effective gait modification methods may well be a combination of an assisted modification and a learned modification taught via a real-time feedback system—for example, variable stiffness shoes with medial thrust gait. Addition of other holistic elements such as strength or flexibility training may be valuable as well. Determination of the best target quantity will be critical for gait modification to make a positive clinical impact.

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