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The Knee

Effects of toe-in and toe-in with wider step width on level walking knee biomechanics in varus, valgus, and neutral knee alignments☆

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ABSTRACT

Background: Increased peak external knee adduction moments exist for individuals with knee osteoarthritis and varus knee alignments, compared to healthy and neutrally aligned counterparts. Walking with increased toe-in or increased step width have been individually utilized to successfully reduce 1st and 2nd peak knee adduction moments, respectfully, but have not previously been combined or tested among all alignment groups. The purpose of this study was to compare toe-in only and toe-in with wider step width gait modifications in individuals with neutral, valgus, and varus alignments.

Methods: Thirty-eight healthy participants with confirmed varus, neutral, or valgus frontal-plane knee alignment through anteroposterior radiographs, performed level walking in normal, toe-in, and toe-in with wider step width gaits. A 3 × 3 (group × intervention) mixed model repeated measures ANOVA compared alignment groups and gait interventions ($p < 0.05$).

Results: The 1st peak knee adduction moment was reduced in both toe-in and toe-in with wider step width compared to normal gait. The 2nd peak adduction moment was increased in toe-in compared to normal and toe-in with wider step width. The adduction impulse was also reduced in toe-in and toe-in with wider step width compared to normal gait. Peak knee flexion and external rotation moments were increased in toe-in and toe-in with wider step width compared to normal gait.

Conclusion: Although the toe-in with wider step width gait seems to be a viable option to reduce peak adduction moments for varus alignments, sagittal, and transverse knee loadings should be monitored when implementing this gait modification strategy.

1. Introduction

Frontal-plane knee varus alignment has been shown to result in increases in the incidence [1] and progression [2] of knee osteoarthritis (KOA). Additionally, varus alignment has been associated with increases of external knee adduction moments (KAM) compared to valgus and neutral alignments [3–5]. During level ground walking, the KAM typically has two distinctive peaks, with the 1st peak associated with loading response and the 2nd with push-off. Larger 1st peak KAMs also exist in patients with medial KOA compared to their healthy counterparts at self-selected walking speeds [5–7], and in severe compared to moderate KOA patients [8,9].

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Both healthy and KOA people with varus alignments have demonstrated increased peak KAMs from 24 to 42% [5,10,11] and increased knee adduction angles up to five degrees [5,12] compared to neutrally aligned participants during level ground walking. Likewise, both healthy and KOA varus alignment groups have shown increases in knee adduction angles compared to neutral [5,6,12] and valgus [5,13] alignment groups during level ground walking.

To reduce frontal plane loading of the knee joint, several gait modification strategies have been implemented in both healthy and KOA populations. The primary target for gait modifications is to reduce the external lever arm of the frontal plane ground reaction forces (GRFs) by bringing the center of the knee closer to the foot center of pressure [14,15], thereby reducing the KAM. Increased internal foot rotation and external rotation during level walking can reduce the frontal plane lever arm during the 1st and 2nd peak KAMs, respectively [14,15]. Increased step width during stair ascent is postulated to bring the knee towards the midline of the body, reducing the lever arms, and both peak KAMs [16]. Since the foot cannot be both internally and externally rotated during stance, a combination of step width and foot progression gait modifications may be advantageous.

Increasing step width alone has reduced peak KAMs in walking [17,18] and stair negotiation [16,19]. In a patient with an instrumented knee replacement, increased step width (not reported) reduced peak KAMs by 4.7% during level walking [18]. During stair ascent and descent, wider step widths (26% leg length) reduced 1st peak KAMs by 11.1% and 5.2%, and reduced 2nd peak KAMs by 20.0% and 8.3% in both KOA and healthy participants [16,19].

Increased internal foot rotation (toe-in) can also reduce 1st peak KAMs [15,20,21], in both healthy and KOA populations during level walking. Toe-in modifications of six degrees [15] to 10° [22], and "maximum comfortable" angles [20,21,23] have reduced 1st peak KAMs by 13% [15,20] to 45% [21]. Interestingly, toe-in has mostly shown little to no effect on 2nd peak KAMs [15,20–22]. Previous research utilizing combinations of several gait modifications such as foot rotation, tibial inclination, trunk sway [24] and foot rotation, step width, trunk sway, and reduced walking speed [25] have been successful in reducing 1st peak KAMs and KAM impulses. However, a drawback of these combinations is that large modifications in trunk sway are necessary to cause significant reductions of KAMs [24,25], while reduced walking speed may not be suitable for goal-oriented locomotion. Combining toe-in with wider step width could be a simpler option that decreases both 1st and 2nd peak KAMs during level walking. Along with previous success found in stair negotiation tasks [26], combining toe-in with wider step width may be an advantageous gait modification for both walking and stair negotiation.

Currently, the relationship between gait modifications during level walking and knee alignment is unknown. Since varus knee alignment is related to the incidence and progression medial KOA, it would be advantageous to discern if gait modifications could be successful in reducing peak KAMs for both healthy and KOA populations with varus alignment during level walking. However, medial KOA is not exclusive to varus alignment [27]. Therefore, it is important to also investigate this relationship in neutral and valgus alignments.

The purpose of this study was to examine effects of combining two gait modification strategies, toe-in and wider step width, on frontal-plane knee loading during level walking in varus, neutral, and valgus knee alignment groups. We hypothesized that 1) toe-in and wider step width would reduce both 1st and 2nd peak KAMs for all alignment groups and 2) the varus alignment group would have increased peak KAMs compared to both neutral and valgus alignment groups, regardless of gait modifications.

2. Methods

2.1. Participants

Thirty-eight healthy individuals with varus, neutral, and valgus knee alignment (Table 1) were recruited from the university campus. The exclusion criteria included major lower extremity musculoskeletal injuries in the past three months, knee pain in the past six months during activities of daily living, diagnosed lower extremity joint arthritis, or body mass index greater than 35. Power analyses for group and condition main effects were computed based on 1.68% bodyweight * height KAM differences between normal and toe-in gaits [15,21] and 0.10 Nm/kg * m KAM differences between healthy neutral and varus alignment groups during normal gait [11] using G * Power [28], and extended to three groups and interventions. At least 12 participants were needed per gait condition and at least seven participants per alignment group to obtain significant main effects with $\beta = 0.80$ and $\alpha = 0.05$. All participants signed an informed consent form, and the university institution review board approved the experimental protocol.

Table 1
Age (yrs.), height (m), mass (kg), BMI, knee mechanical axis angle (deg.), and walking speed (m/s) comparisons between groups: Mean (SD).

	Neutral	Valgus	Varus	*p*-Value
Number	15	13	10	–
Age	23.7 (0.8)	22.3 (1.0)	24.7 (0.9)	0.2080
Height	1.75 (0.1)	1.74 (0.1)	1.77 (0.1)	0.6200
Mass	72.8 (14.7)	72.2 (12.6)	73.4 (14.8)	0.9800
BMI	23.6 (3.1)	23.7 (2.5)	23.3 (4.1)	0.9400
Knee mechanical axis angle*	179.4 (0.7)	183.6 (1.0)	174.0 (1.4)	<**0.0001**
Walking speed	1.39 (0.14)	1.45 (0.18)	1.42 (0.16)	0.6283

* The knee mechanical axis angle was significantly different between all groups.

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