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ORIGINAL ARTICLE

Combined Effects of a Valgus Knee Brace and Lateral Wedge Foot Orthotic on the External Knee Adduction Moment in Patients With Varus Gonarthrosis

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Abstract

Objective: To test the hypothesis that a custom-fit valgus knee brace and custom-made lateral wedge foot orthotic will have greatest effects on decreasing the external knee adduction moment during gait when used concurrently.

Design: Proof-of-concept, single test session, crossover trial.

Setting: Biomechanics laboratory within a tertiary care center.

Participants: Patients (n = 16) with varus alignment and knee osteoarthritis (OA) primarily affecting the medial compartment of the tibiofemoral joint (varus gonarthrosis).

Interventions: Custom-fit valgus knee brace and custom-made full-length lateral wedge foot orthotic. Amounts of valgus angulation and wedge height were tailored to each patient to ensure comfort.

Main Outcome Measures: The external knee adduction moment (% body weight [BW]*height [Ht]), frontal plane lever arm (cm), and ground reaction force (N/kg), determined from 3-dimensional gait analysis completed under 4 randomized conditions: (1) control (no knee brace, no foot orthotic), (2) knee brace, (3) foot orthotic, and (4) knee brace and foot orthotic.

Results: The reduction in knee adduction moment was greatest when concurrently using the knee brace and foot orthotic (effect sizes ranged from 0.3 to 0.4). The mean decrease in first peak knee adduction moment compared with control was .36% BW*Ht (95% confidence interval [CI], −.66 to −.07). This was accompanied by a mean decrease in frontal plane lever arm of .59cm (95% CI, −.94 to −.25).

Conclusions: These findings suggest that using a custom-fit knee brace and custom-made foot orthotic concurrently can produce a greater overall reduction in the knee adduction moment, through combined effects in decreasing the frontal plane lever arm.

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Knee osteoarthritis (OA) is a leading cause of disability with substantial personal and economic costs.[1,2] The need to develop strategies for controlling long-term pain, impaired physical function, and rising costs is paramount.[1,2] Nonpharmaceutical and nonoperative interventions with minimal side effects are encouraged as early treatment options for individuals with knee OA.[1,3] Knee braces and foot orthotics are common examples of such treatments.

The medial compartment of the tibiofemoral joint is more commonly affected by OA than the lateral compartment, largely

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Table 1 Means ± SD and effect sizes for the knee adduction moment from studies examining the effect of unloader knee braces

Author (Year)	N	Intervention	Knee Adduction Moment Without Brace	Knee Adduction Moment With Brace	Effect Size*
Lindenfeld (1997)[17]	11	Off-the-shelf brace	Peak = 4.0±0.75 (%BW*Ht)	Peak = 3.5±0.8 (%BW*Ht)	0.6
Self (2000)[18]	5	Custom brace	Peak = 0.555±0.163 (Nm/kg)	Peak = 0.49±0.158 (Nm/kg)	0.4
Pollo (2002)[19]	11	Normal valgus brace	Peak = 55.3±18.6 (Nm)	Peak = 54.8±17.7 (Nm)	0.02
		4° Valgus brace		Peak = 52.6±17.9 (Nm)	0.1
		4° Tight valgus brace		Peak = 51.1±16.9 (Nm)	0.2
		8° Valgus brace		Peak = 51.7±16.9 (Nm)	0.2
Draganich (2006)[20]	10	Off-the-shelf brace	Peak = 6.9%±1.9% (%BW*Ht)	Peak = 6.6%±2.2% (%BW*Ht)	0.2
		Custom brace		Peak = 5.9%±2.0% (%BW*Ht)	0.5
Schmalz (2010)[21,†]	16	Custom brace	Peak = 0.63 (Nm/kg)	Peak = 0.60 (Nm/kg)	‡
Fantini Pagani (2010)[22]	11	4° Valgus brace	1st Peak = 0.52±0.16 (Nm/kg)	1st Peak = 0.53±0.15 (Nm/kg)	−0.1
			2nd Peak = 0.48±0.17 (Nm/kg)	2nd Peak = 0.40±0.19 (Nm/kg)	0.5
			Impulse = 30.6±10.8 (Nm/kg*%stance)	Impulse = 26.6±12.0 (Nm/kg*%stance)	0.4
		Neutral flexible		1st Peak = 0.50±0.15 (Nm/kg)	0.1
				2nd Peak = 0.42±0.19 (Nm/kg)	0.4
				Impulse = 26.6±11.7 (Nm/kg*%stance)	0.4
Toriyama (2011)[23]	19	Off-the-shelf brace	1st Peak = 0.54±0.20 (Nm/kg)	1st Peak = 0.48±0.19 (Nm/kg)	0.3
			2nd Peak = 0.48±0.19 (Nm/kg)	2nd Peak = 0.48±0.19 (Nm/kg)	0
Fantini Pagani (2011)[15]	10	4° Valgus brace	1st Peak = 0.41±0.15 (Nm/kg)	1st Peak = 0.40±.16 (Nm/kg)	0.1
			2nd Peak = 0.38±0.16 (Nm/kg)	2nd Peak = 0.31±0.16 (Nm/kg)	0.4
		8° Valgus brace		1st Peak = 0.38±0.12 (Nm/kg)	0.2
				2nd Peak = 0.30±0.16 (Nm/kg)	0.5

* Effect size = (Mean change between the control and intervention conditions)/(Pooled SD).
† Estimated data from figure.
‡ Insufficient data reported to calculate effect size.

because of the greater loads typically borne by that compartment during walking. Even healthy, asymptomatic individuals without malalignment experience greater load in the medial compartment.[4] However, this imbalance in load distribution is exacerbated with varus alignment, an important risk factor for medial compartment knee OA.[5] With the use of 3-dimensional gait analysis, the calculated external adduction moment about the knee during walking reflects the asymmetric loading of the tibiofemoral joint.[4,6] Indeed, although limitations exist,[7] the external knee adduction moment has emerged as a valid,[6] reliable[8] proxy for dynamic load on the medial compartment and a predictor of radiographic and magnetic resonance imaging means of disease progression.[9,10]

The knee adduction moment during walking is calculated using principles of inverse dynamics[11] and is influenced primarily by the frontal plane ground reaction force and its lever arm.[4,12,13] The line of action of the ground reaction force passes from the center of pressure of the foot to the area of the center of mass of the body, and typically remains medial to the knee joint throughout stance. The perpendicular distance between the knee joint center and the line of action of the ground reaction force determines the magnitude of its lever arm in the frontal plane. Increases in varus alignment shift the knee joint laterally with respect to the ground reaction force line of action, thereby increasing the magnitude of the lever arm and external knee adduction moment.

List of abbreviations:

BW body weight
CI confidence interval
Ht height
OA osteoarthritis

Although their proposed mechanisms are different, valgus knee braces and lateral wedge foot orthotics both aim to decrease the knee adduction moment. Importantly, while there may be a number of contributing factors, both knee braces and foot orthotics are intended to decrease the frontal plane lever arm by acting on the knee and foot, respectively.[14-16] Biomechanical studies suggest valgus knee braces can indeed decrease the knee adduction moment, although results vary widely and the effect sizes (ie, mean change divided by the pooled SD of the control condition) are generally small to moderate (table 1).[15,17-23] Biomechanical studies suggest that lateral wedge foot orthotics can also decrease the knee adduction moment. Similarly, results vary widely and effect sizes are generally small (table 2).[14-16,24-32]

The results of clinical trials evaluating knee braces and foot orthotics for medial compartment knee OA are also inconsistent.[33-38] Although there are some encouraging findings with respect to pain and function,[34,36,38-40] the effect sizes for those studies are generally small to moderate. Importantly, difficulties with comfort may partially explain why effect sizes are low.[33,36-38] Some biomechanical evidence suggests that knee braces with greater valgus angulation, and foot orthotics with larger lateral wedges, provide greater reductions in the knee adduction moment in a dose-response relationship.[15,19,25,41,42] Unfortunately, studies also suggest that larger knee brace angulations and foot orthotic wedge heights (ie, greater doses) are associated with less comfort.[25,27,33]

Table 2 Means ± SD and effect sizes for the knee adduction moment from studies examining the effect of lateral heel wedges, insoles, and variable stiffness shoes

Author (Year)	N	Intervention	Knee Adduction Moment Without Orthotic	Knee Adduction Moment With Orthotic	Effect Size*
Maly (2002)[24]	12	5° Heel wedge	Peak = 0.48±0.13 (Nm/kg)	Peak = 0.47±0.11 (Nm/kg)	0.1
		5° Wedged orthotic		Peak = 0.50±0.11 (Nm/kg)	−0.2
Kerrigan (2002)[25]	15	5° Wedged insole	1st Peak = 0.396±0.084 (Nm/kg*m)	1st Peak = 0.375±0.090 (Nm/kg*m)	0.2
			2nd Peak = 0.339±0.078 (Nm/kg*m)	2nd Peak = 0.317±0.076 (Nm/kg*m)	0.3
		10° Wedged insole		1st Peak = 0.363±0.083 (Nm/kg*m)	0.4
				2nd Peak = 0.312±0.078 (Nm/Kg*m)	0.3
Shimada (2006)[26]	23	10-mm Wedged insole	Peak = 0.90±0.20 (Nm/kg)	Peak = 0.86±0.19 (Nm/kg)	0.2
Butler (2007)[27]	20	Custom wedged orthotic	1st Peak = 0.379±0.128 (Nm/kg*m)	1st Peak = 0.346±0.122 (Nm/kg*m)	0.3
			2nd Peak = 0.245±0.078 (Nm/kg*m)	2nd Peak = 0.240±0.071 (Nm/kg*m)	0.1
Kakihana (2007)[28]	51	6° Wedged insole	Peak = 0.218±0.049 (Nm/kg*m)	Peak = 0.205±0.049 (Nm/kg*m)	0.3
Erhart (2008)[29]	79	Variable stiffness shoe	Peak (slow) = 2.73±0.91 (%BW*Ht)	Peak (slow) = 2.67±0.92 (%BW*Ht)	0.1
			Peak (normal) = 2.87±0.99 (%BW*Ht)	Peak (normal) = 2.74±0.95 (%BW*Ht)	0.1
			Peak (fast) = 3.28±1.17 (%BW*Ht)	Peak (fast) = 3.07±1.11 (%BW*Ht)	0.2
Hinman (2008)[30]	13	5° Heel wedge	1st Peak = 3.60±0.90 (%BW*Ht)	1st Peak = 3.33±0.69 (%BW*Ht)	0.3
			2nd Peak = 1.98±0.82 (%BW*Ht)	2nd Peak = 1.84±0.76 (%BW*Ht)	0.2
		5° Wedge orthotic		1st Peak = 3.17±0.61 (%BW*Ht)	0.6
				2nd Peak = 1.70±0.76 (%BW*Ht)	0.4
Hinman (2009)[31]	20	5° Wedged insole	1st Peak = 3.82±0.62 (%BW*Ht)	1st Peak = 3.62±0.59 (%BW*Ht)	0.3
			2nd Peak = 2.45±0.78 (%BW*Ht)	2nd Peak = 2.32±0.84 (%BW*Ht)	0.2
			Impulse = 1.38±0.49 (%BW*Ht*s)	Impulse = 1.31±0.48 (%BW*Ht*s)	0.1
Jenkyn (2011)[14]	32	Variable stiffness shoe	Peak = 2.76±1.07 (%BW*Ht)	Peak = 2.57±1.00 (%BW*Ht)	0.2
Fantini Pagani (2011)[15]	10	4° Wedged insole	1st Peak = 0.41±0.15 (Nm/kg)	1st Peak = 0.38±0.13 (Nm/kg)	0.2
			2nd Peak = 0.38±0.16 (Nm/kg)	2nd Peak = 0.35±0.16 (Nm/kg)	0.2
Abdallah (2011)[32]	21	6° Wedged insole	Peak = 0.66±0.16 (Nm/kg)	Peak = 0.60±0.14 (Nm/kg)	0.4
		11° Wedged insole		Peak = 0.63±0.15 (Nm/kg)	0.2
Hinman (2012)[16]	73	5° Wedge insole	Peak = 3.82±0.78 (%BW*Ht)	Peak = 3.60±0.75 (%BW*Ht)	0.3
			Impulse = 1.26±0.37 (%BW*Ht*s)	Impulse = 1.18±0.38 (%BW*Ht*s)	0.2

* Effect size = (Mean change between the control and intervention conditions)/(Pooled SD).

A novel treatment strategy may be to use a valgus knee brace and lateral wedge foot orthotic concurrently, where both are custom-fit to doses that ensure comfort. Recent studies suggest that when tested separately, valgus knee braces,[15] lateral wedge foot orthotics,[15,16] and variable stiffness shoes[14] decrease the external knee adduction moment through decreases in its frontal

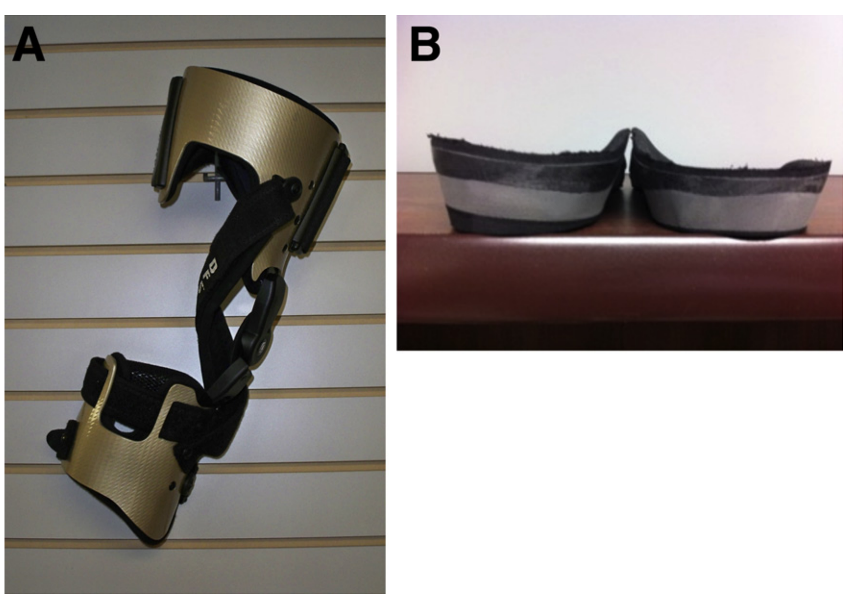

Fig 1 (A) Custom-fit valgus knee brace (Össur Unloader XT Lite[a]). (B) Custom-made full-length lateral wedge insoles (only the left foot orthotic has a lateral wedge).

plane lever arm. This could theoretically be achieved by altering the position of the knee joint center medially (eg, with the use of a knee brace) or by altering the orientation of the ground reaction force laterally (eg, with the use of a foot orthotic). It is therefore possible that there may be additive effects on decreasing the knee adduction moment when these interventions are used together. Accordingly, the primary objective of this proof-of-concept study was to test the hypothesis that a custom-fit valgus knee brace and custom-made lateral wedge foot orthotic will have greatest effects on decreasing the external knee adduction moment during gait when used concurrently. The secondary objective was to explore changes in the frontal plane ground reaction force and its lever arm.

Methods

Participants

Patients with varus alignment, symptomatic medial compartment knee OA, and who were provided with a prescription for a valgus knee brace were recruited from a tertiary care center specializing in orthopedics. Standing hip-to-ankle anteroposterior radiographs were used to assess frontal plane alignment.[43] Varus alignment was defined as a mechanical axis angle of $\geq 1^\circ$ varus. Kellgren and Lawrence grades were also determined from the full-length standing radiographs.[44] All patients had to have clinical and radiographically confirmed knee OA according to the Altman classification system,[45] with greater severity in the medial compartment of the tibiofemoral joint (ie, varus gonarthrosis). All patients had to have pain localized to the medial side of the tibiofemoral joint, and greater joint space narrowing on the medial side compared with the lateral. Ethics approval was obtained from the institution's ethics review board, and all patients signed informed consent before testing.

Valgus knee brace fitting

All patients were provided with a custom-fit valgus knee brace[a] (fig 1A) by a trained technician (R.F.W.) at least 6 months before gait testing. The brace was designed on a 3-point bending

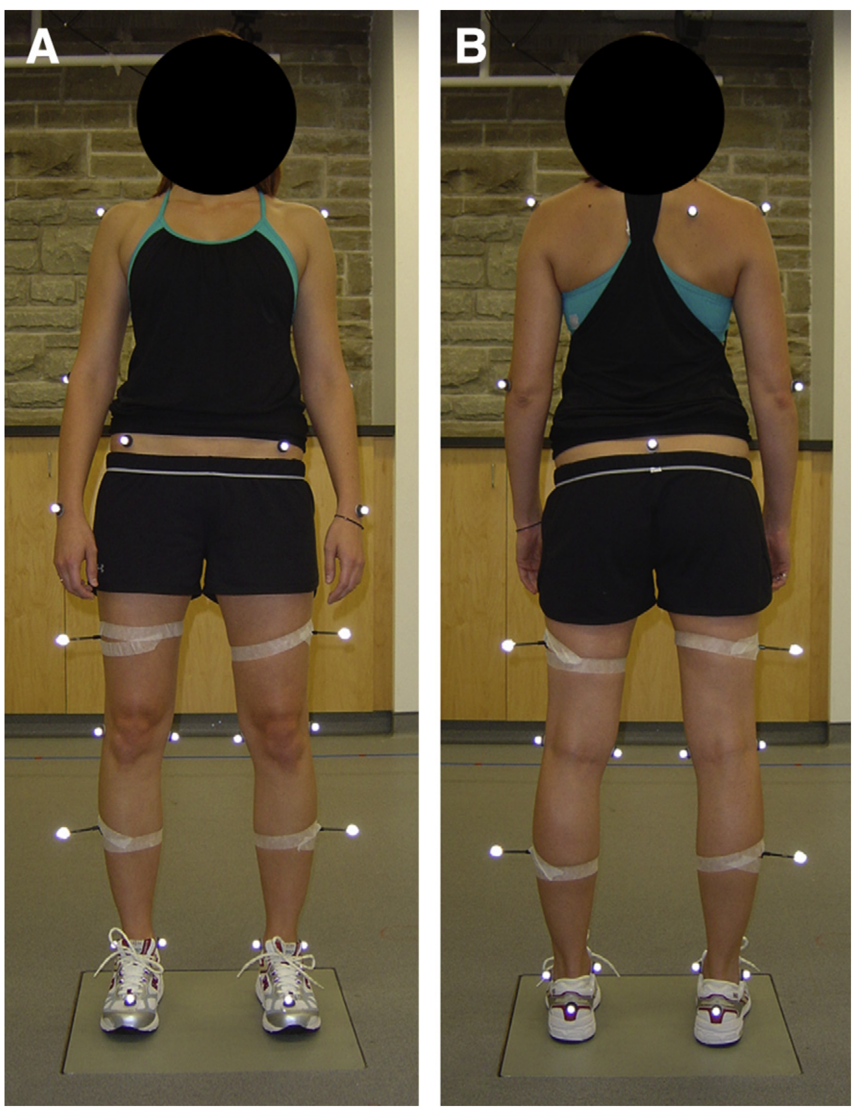

Fig 2 Anterior (A) and posterior (B) views of the modified Helen Hayes marker set used for 3-dimensional gait analysis.

mechanism to apply a medially directed force to the lateral aspect of the knee. A hard shell cuff was located around the thigh and shank with a medially placed hinge and lateral crossover strap. A casted mold was made from the weight-bearing limb for each patient and sent to the brace manufacturer. From the mold, the custom-fit, adjustable brace was fabricated and set to a valgus angle between 4° and 7°. At the clinic, the patients walked with the brace, and the technician adjusted the amount ±2° to ensure patient comfort. Patients were instructed to wear the brace while they were awake for activities that had been troublesome to them in the past.[34]

Lateral wedge foot orthotic fitting

Full-length custom-made foot orthotics[b] (fig 1B) were made from an ethyl vinyl acetate with a 55 Shore A durometer hardness using a fully weight-bearing plaster positive mold of each patient's foot. A pedorthist (C.E.D.) fitted the orthotic to each patient during weight-bearing and walking while also wearing the custom-fit knee brace. The pedorthist initially assessed the subjective effects of the foot orthotics using 3 prefabricated full-length lateral wedges of 3, 6, and 9mm. The goal was to provide a custom-made foot orthotic with the maximum wedge height while maintaining comfort. The unaffected leg was also fitted for a foot orthotic with no wedge.

Testing protocol

As patients with prescriptions for valgus knee braces were recruited from this center, we followed the present clinic's valgus knee bracing practice, which suggests a trial of 6 months' use.[34] Afterward, patients returned to the clinic and were provided with the custom-made, full-length lateral wedge foot orthotic. The pedorthic assessment, foot orthotic fabrication, and gait testing using both knee brace and foot orthotic took place within a 1-week period. Four different gait conditions were tested during 1 session: (1) control (no knee brace, no foot orthotic), (2) custom-fit valgus knee brace, (3) custom-made lateral wedge foot orthotic, and (4) both knee brace and foot orthotic. A balanced Latin square design was used to randomize patients to the order of testing conditions.[46]

Gait analysis

All patients underwent 3-dimensional gait analysis using an 8-camera motion capture system[c] synchronized with a floor-mounted force platform.[d] Twenty-two passive-reflective markers were placed on the patient using a Helen Hayes marker set,[47] with modifications illustrated in figure 2. Bilateral markers on the medial aspect of the knee joint line and medial malleolus were used during an initial static trial to identify knee and ankle joint centers, respectively. These 4 markers were removed before gait testing. Patients independently donned and doffed the knee brace according to the manufacturer's instructions. The knee brace did not interfere with markers during walking, or during donning and doffing (fig 3). In each testing condition, the participant walked at a preferred, self-selected pace until 5 forceplate strikes were recorded. Footwear[e] was standardized for all patients and worn throughout each testing condition.

The external adduction moment about the knee was calculated by commercial software[c] from the kinematic (sampled at

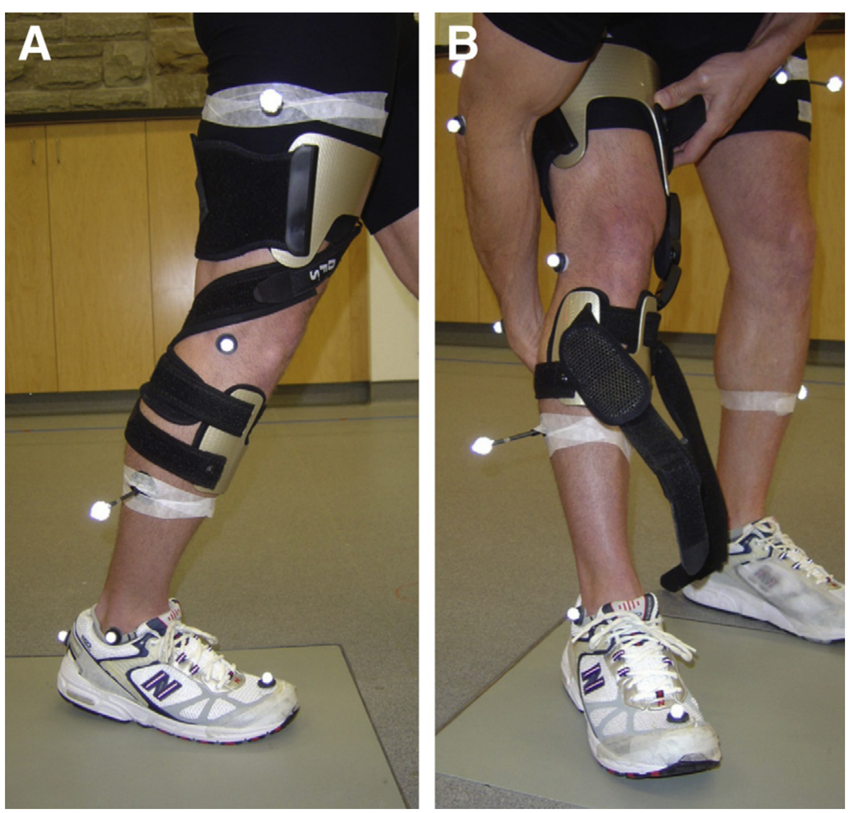

Fig 3 (A) Lateral view of the right lower extremity illustrating brace and marker positions during walking. (B) Donning and doffing of the knee brace did not interfere with markers.

60Hz) and kinetic data (sampled at 1200Hz) using inverse dynamics. Each lower limb segment (foot, shank, and thigh) was modeled as a rigid body with a local coordinate system that coincided with anatomically relevant axes. Inertial properties of each limb segment were approximated anthropometrically, and translations and rotations of each segment were reported relative to neutral positions defined during the initial standing static trial. For each trial, the knee adduction moment waveform was normalized to body weight and height (%BW*Ht), plotted over 100% of stance, and inspected visually. The peak magnitudes of the external knee adduction moment in the first and second halves of stance were identified using an algorithm that identified values immediately preceded by a minimum of 5 continuously ascending values and followed by a minimum of 5 continuously descending values. If no identifiable peak occurred in a given half of stance, no knee adduction moment value for that half of stance was recorded. The entire knee adduction moment waveform (not normalized to percent stance) was also summarized as its angular impulse (ie, the area under the curve in %BW*Ht*s). Test-retest reliability of these knee adduction moment measures is excellent.[8,48]

Given their strong influence on the knee adduction moment, the frontal plane ground reaction force, its lever arm, and gait speed were also calculated.[4,12,13] All gait variables were averaged across the 5 trials. Pain was assessed at rest (ie, before gait testing began) and after walking in each condition. A numeric rating scale was used, with 0 representing no pain and 10 representing the worst possible pain. Patient preference for condition was also assessed.

Table 3 Demographics and clinical characteristics

Characteristics	Values
Age (y)	55±7.0
BMI (kg/m^2)	32±6.2
Mechanical axis angle (deg)*	6.6±3.3
Pain at rest (0–10)	1.2±1.3
Kellgren and Lawrence grade (no. of patients)†	
0/1/2/3/4	0/2/5/6/3
KOOS (0–100)‡	
Pain	49.3±15.9
Symptoms	37.5±11.2
Activities of daily living	54.3±15.3
Sport and recreation	18.8±14.0
Quality of life	23.8±13.7

NOTE. Values are mean ± SD or as otherwise indicated.

Abbreviations: BMI, body mass index; KOOS, Knee Injury and Osteoarthritis Outcome Score.

* A positive value represents varus alignment.

† Kellgren and Lawrence grade of OA severity is a radiographic classification system for osteoarthritis. Grade 1, doubtful narrowing of joint space and possible osteophytic lipping; grade 2, definite narrowing of joint space and possible osteophytic lipping; grade 3, moderate multiple osteophytes, definite narrowing of joint space, some sclerosis, and possible deformity of bone contour; grade 4, large osteophytes, marked narrowing of joint space, severe sclerosis, and definite deformity of bone contour.

‡ The KOOS is a knee-specific measure administered to patients to assess opinions of their knees and general health. The score is normalized out of 100 for each subscale (100 represents no symptoms; 0 represents extreme symptoms).

Data analysis

We first plotted ensemble average (n = 16) waveforms throughout stance for the knee adduction moment, frontal plane ground reaction force, and lever arm during each test condition. We then calculated means and SDs, and mean changes from the control condition with 95% confidence intervals (CIs), for each condition. Changes in the knee adduction moment were evaluated statistically using paired *t* tests. Given the exploratory nature of this study, we maintained the value for statistical significance at

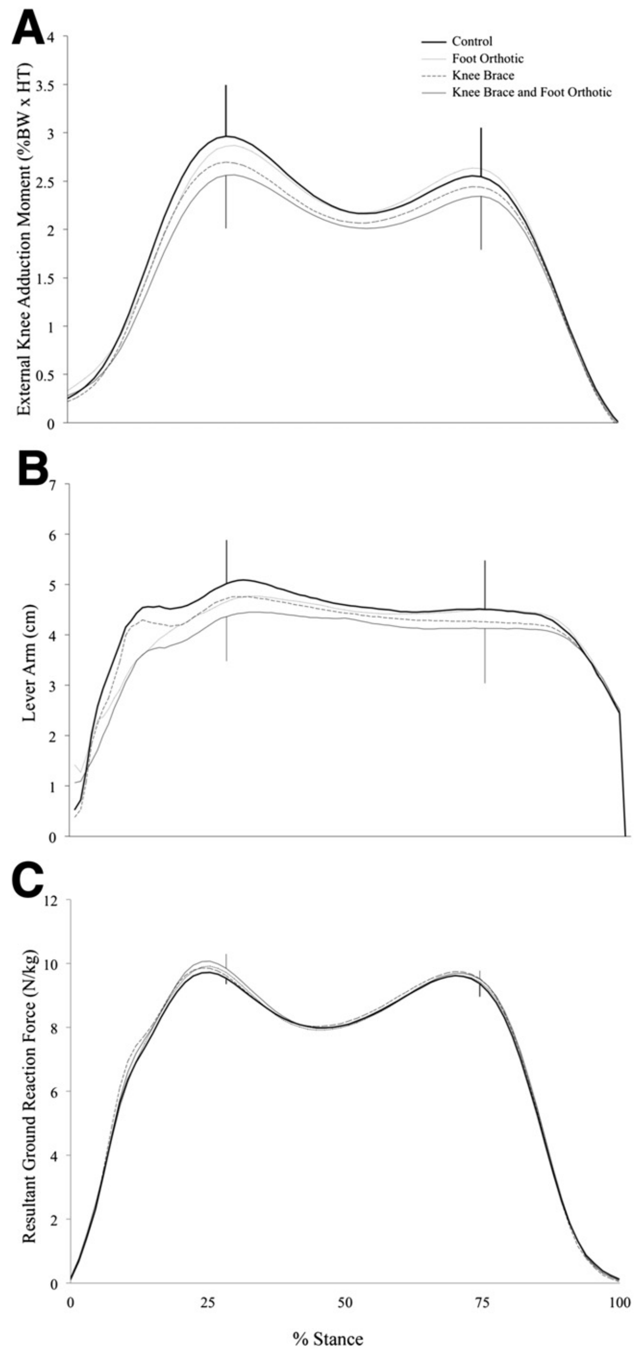

Fig 4 Ensemble averages (n = 16) of (A) the knee adduction moment, (B) frontal plane lever arm, and (C) resultant ground reaction force throughout stance. Vertical bars represent 95% CIs.

$P<.05$. The remaining measures were considered secondary outcomes used to help explain the knee adduction moment findings and were not evaluated with statistical testing.

Results

Patient demographics and clinical characteristics are presented in table 3. Sixteen patients (8 men, 8 women) met our inclusion criteria and participated in the study. Eight 9-mm lateral wedge foot orthotics, seven 6-mm lateral wedge foot orthotics, and one 3-mm lateral wedge foot orthotic were custom-made for patients. The final knee brace angles ranged from 2° to 9° of valgus. Ensemble average curves for the external knee adduction moment, frontal plane lever arm, and ground reaction force are illustrated in figure 4. Descriptive statistics for all measures during each test condition are presented in table 4. All 16 patients had an identifiable first peak knee adduction moment. Twelve to 15 patients had an identifiable second peak knee adduction moment, depending on the test condition (see table 4). Mean changes (95% CI) compared with the control are presented in table 5. A statistically significant reduction in knee adduction moment (first peak and angular impulse) was only present when concurrently using the knee brace and foot orthotic. Nine patients stated that they preferred wearing the knee brace and foot orthotic concurrently. Five patients preferred the foot orthotic only. One patient preferred the knee brace only. One patient preferred wearing neither device.

Discussion

The present findings support the concept of using a custom-fit knee brace and custom-made foot orthotic concurrently to enhance the magnitude of reduction in the knee adduction moment. We are aware of limited previous research evaluating the combined effects of knee braces and foot orthotics. Schmalz et al[49] reported changes in the knee adduction moment during walking with combined use of a heel wedge and rigid ankle-foot orthosis in healthy participants. In a recent randomized crossover trial, Hunter et al[50] reported that the combined use of a valgus knee brace, neutral foot orthotic, and motion control shoe significantly improved knee pain more than placebo treatment.

The present results are consistent with the suggestion that patients with knee OA may receive greater load reductions in the medial compartment by using a valgus knee brace and lateral wedge foot orthotic simultaneously. The largest change in the knee adduction moment occurred at its first peak (.36% BW*Ht) and represented a 12% reduction. It is presently unclear whether this size of a change is clinically important. A 12% reduction might be considered disappointing given that 2 interventions were combined. Alternatively, previous researchers[33,51] have argued that even smaller changes are potentially important given the thousands of steps taken per day and the relationship between high knee adduction moments and future disease progression.

The concurrent use of the valgus knee brace and lateral wedge foot orthotic resulted in effect sizes ranging from 0.3 to 0.4. These are comparable to previously reported effect sizes for these devices when used on their own (see tables 1 and 2). Importantly, the magnitudes of the valgus knee brace angulation and the foot orthotic wedge size were determined in the present study by patient comfort. Therefore, although it is unclear whether greater reductions in knee load per individual step taken can be achieved while wearing both devices, maintaining patient comfort with similar effect sizes may improve patient compliance and produce a greater overall, cumulative decrease in load with prolonged use.

Although the secondary outcomes must be interpreted cautiously, the present findings also suggest that decreases in the knee adduction moment observed with both devices are brought about through decreases in the frontal plane lever arm. We are aware of 2 previous studies[15,16] that quantified changes in the frontal plane lever arm to evaluate mechanisms for decreasing the knee adduction moment with knee brace or lateral wedge foot orthotic use. Fantini Pagani et al[15] and Hinman et al[16]

Table 4 Descriptive statistics for outcome measures during different testing conditions

	Control	Orthotic	Brace	Orthotic and Brace
Primary Outcome Measure				
KAM				
1st Peak (%BW*Ht)	3.08±1.09	2.98±1.05	2.82±0.97	2.72±1.12
2nd Peak (%BW*Ht)*	2.99±0.81	2.78±1.01	2.61±0.94	2.42±1.24
Impulse (%BW*Ht*s)	1.45±0.52	1.44±0.52	1.37±0.46	1.32±0.58
Secondary Outcome Measures				
Lever arm (cm)				
Peak value during stance	5.63±1.85	5.45±1.82	5.40±1.84	5.11±2.07
Value at 1st peak KAM	5.09±1.75	4.79±1.67	4.73±1.73	4.49±1.71
Value at 2nd peak KAM	5.15±1.95	4.79±1.96	4.44±2.13	4.46±2.37
Resultant ground reaction force (N/kg)				
Peak value during stance	9.98±0.92	10.34±0.78	10.17±0.98	10.43±1.00
Value at 1st peak KAM	9.80±0.99	9.87±0.88	9.54±1.30	9.96±1.10
Value at 2nd peak KAM	9.88±0.50	9.73±0.57	9.83±0.54	9.83±0.57
Gait speed (m/s)	1.15±0.17	1.16±0.17	1.16±0.16	1.17±0.18
NRS pain (0–10)	3.44±1.86	3.06±2.21	3.31±2.30	3.69±2.06

NOTE. Values are mean ± SD.
Abbreviations: KAM, knee adduction moment; NRS, numeric rating scale.
* An identified 2nd peak KAM varied between the control (n=12), orthotic (n=13), brace (n=13), and orthotic and brace (n=15) conditions.

Table 5 Change from control for the different testing conditions for each outcome measure

	Orthotic	Brace	Orthotic and Brace
Primary Outcome Measures			
KAM			
1st Peak (%BW*Ht)	−.10 (−.29 to .08)	−.26 (−.59 to .07)	−.36 (−.66 to −.07)
2nd Peak (%BW*Ht)*	.08 (−.24 to .39)	−.12 (−.38 to .13)	−.32 (−.73 to .07)
Impulse (%BW*Ht*s)	−.003 (−.11 to .10)	−.08 (−.21 to .05)	−.13 (−.23 to −.02)
Secondary Outcome Measures			
Lever arm (cm)			
Peak value during stance	−.18 (−.44 to .09)	−.23 (−.60 to .14)	−.52 (−.89 to −.15)
Value at 1st peak KAM	−.29 (−.65 to .06)	−.36 (−.74 to .02)	−.59 (−.94 to −.25)
Value at 2nd peak KAM	−.03 (−.37 to .31)	−.37 (−.82 to .08)	−.66 (−1.37 to .04)
Resultant ground reaction force (N/kg)			
Peak value during stance	.35 (.10 to .60)	.19 (.02 to .35)	.45 (.29 to .60)
Value at 1st peak KAM	.08 (−.18 to .33)	−.26 (−.92 to .40)	.16 (−.18 to .49)
Value at 2nd peak KAM	−.07 (−.19 to .06)	.05 (−.12 to .21)	.001 (−.18 to .19)
Gait speed (m/s)	.01 (−.02 to .04)	.01 (−.02 to .04)	.02 (−.001 to .05)
NRS pain (0—10)	−.38 (−.92 to .17)	−.13 (−.82 to .57)	.25 (−.44 to .94)

NOTE. Values are mean (95% CI).
Abbreviations: KAM, knee adduction moment; NRS, numeric rating scale.
* Note that the change scores at the 2nd peak KAM do not match the difference between values in table 4 because the sample sizes are different.

reported decreases in the lever arm at the first peak knee adduction moment of .25cm and .29cm, respectively, when patients wore lateral wedge foot orthotics. Those results are very similar to the mean changes in the lever arm observed in the present study (see table 5). Of note, the combined effect (using both the foot orthotic and the knee brace) on reducing the frontal plane lever arm appeared to be additive (see table 5). Toda,[52] Hinman,[53] and van Raaij[38] and colleagues have suggested a variety of ways individual subjects using orthotics experienced decreases in the frontal plane lever arm, including increased hip adduction, a more vertically oriented ground reaction force in the frontal plane, and a lateral shift in the center of pressure.[15,16] Future research is required to determine whether such mechanisms contribute to the combined effects of knee braces and foot orthotics.

Study limitations

Valgus knee braces and lateral wedge foot orthotics may affect knee joint loads in ways not evaluated in the present study. For example, the knee brace may absorb external forces,[54] decrease muscle co-contraction,[55] or both, and contribute to decreased internal knee joint loads without necessarily being detected by the external knee adduction moment. Also, although the knee adduction moment is strongly correlated to internal contact forces in the medial compartment of the tibiofemoral joint,[6] a reduction in the knee adduction moment does not necessarily guarantee a reduction in medial compartment load.[7] The patients in this study wore the custom-fit knee brace for a longer period than the custom-made foot orthotic, and it is unclear how this may have affected results. We do not have data on the specific final angle of brace adjustment to correlate to observed biomechanical findings, nor do we have data on adherence or adverse events. Although we speculate that improved comfort may improve compliance and result in greater reductions in overall cumulative knee joint loading, this requires future study.

Conclusions

The present findings suggest that using a custom-fit valgus knee brace and custom-made lateral wedge foot orthotic concurrently can produce a greater overall reduction in the knee adduction moment, through combined effects in decreasing the frontal plane lever arm. The observed changes were small, and the clinical importance is presently unclear; however, given the reported difficulties with compliance with braces and orthotics, these results do lend support to future work investigating potential additive effects of combined interventions tailored to ensure patient comfort.

Suppliers

a. Össur Corporate, 19762 Pauling Rd, Foothill Ranch, CA 92610-2611.
b. Sole Science, 1182 Frances St, London, ON N5W 2M1, Canada.
c. Motion Analysis Corp, 3617 Westwind Blvd, Santa Rosa, CA 95403.
d. Advanced Medical Technology Inc, 176 Waltham St, Watertown, MA 02472-4800.
e. New Balance, 3660 Hurontario St, Mississauga, ON L5B 3C4, Canada.

Keywords

Biomechanics; Braces; Gait; Orthoses; Osteoarthritis, knee; Rehabilitation

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