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Reduction of Medial Compartment Loads with Valgus Bracing of the Osteoarthritic Knee

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ABSTRACT

Background: Patients with medial compartment osteoarthritis of the knee may be treated nonoperatively with adjustable valgus bracing.
Hypothesis: Valgus bracing reduces load on the medial compartment through the application of an external valgus moment about the knee, resulting in pain relief.
Study Design: Prospective cohort study.
Methods: Eleven patients were tested using an instrumented brace and three-dimensional gait analysis. We measured the valgus moment applied by the adjustable valgus brace and determined the compressive load in the medial compartment. We also documented the effects of increased valgus alignment of the brace and increased strap tension on load sharing. Pain and activity levels were also recorded.
Results: Pain and activity level improved in all subjects with valgus bracing. During gait, valgus bracing reduced the net varus moment about the knee by an average of 13% (7.1 N·m) and the medial compartment load at the knee by an average of 11% (114 N) in the calibrated 4° valgus brace setting. Increasing valgus alignment with the adjustable brace had a greater effect on the medial compartment load than did increasing strap tension.
Conclusion: Adjustable valgus bracing was effective in reducing medial compartment load and subsequent pain while also improving knee function in a group of patients with osteoarthritis.

Osteoarthritis is the most common form of the articular disorders that affect tens of millions of United States citizens.[16] It has recently been reported that 6% of United States adults 30 years of age or older, or approximately 9.7 million people, have symptomatic osteoarthritis of the knee.[4] When the knee joint is affected, osteoarthritis appears to be more prevalent in the medial compartment than in the lateral compartment.[1,5,7] During normal gait, except for the occurrence of a brief valgus moment after initial contact, the knee joint is subjected to an external varus moment throughout the stance phase.[24] The external varus moment is responsible for shifting the load from the lateral to the medial compartment and can occur even in the presence of a valgus deformity at the knee.[6,12,19] The predominance of a varus moment and the concomitant increased medial compartment joint loads are thought to be responsible, in part, for the greater incidence of osteoarthritis in this knee joint compartment.

The external varus moment about the knee depends on mechanical alignment of the knee as well as on the ground reaction force. In patients with medial compartment osteoarthritis, the medial joint space narrows as a result of articular cartilage degeneration and as the mechanical alignment shifts toward varus. This shift can result in an even greater external varus moment about the knee than is seen on the unaffected side or in a control population[6,12] unless the patient develops a compensatory gait pattern that involves toeing out.[23] Furthermore, a reduction in proprioception,[2] which can predispose the joint to abnormal kinematics, combined with this increased external varus moment, which shifts more load to the affected compartment, may further facilitate joint degeneration in patients with osteoarthritis.

Patients who have a diagnosis of isolated medial compartment osteoarthritis of the knee are confronted with a variety of treatment options. Nonsurgical mechanical interventions include the use of canes, lateral shoe wedges, and valgus knee bracing. Valgus bracing was devised to provide medial compartment pain relief by reducing the load on the medial compartment through the application of an opposing external valgus moment about the knee

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joint. Several studies investigating the clinical efficacy of valgus bracing have reported that patients experience significant pain relief and improvement in physical function.[8–10,13,14,17,18,20] Functional pain improvement during walking or on stairs has been reported at 1 week,[9] 9 weeks,[8] 12 weeks,[9] and 12 months.[8] Significant improvements in pain and function assessed with validated knee instruments have been reported at 3 months,[13] 6 months,[14] and 12 months.[18] Finally, significant reduction of pain during activities of daily living has been reported at 4 weeks,[17] 6 weeks,[10] 9 weeks,[8] and 12 months.[8]

Previous gait studies of patients treated with valgus bracing have measured alterations in the external moment but have not quantified the load taken up by the brace or determined the changes in medial compartment force.[3,8,17,22] Biomechanical results, depending on the engineering design of the knee brace, range from no differences in dynamic gait parameters[8] and no significant difference in varus moment between sham bracing (no valgus correction) and valgus bracing[20] to a significant improvement in gait symmetry[3] and a reduction in external varus moments.[17,21,22] In addition, no previous study has quantified the effect of adjustable valgus brace alignment on changes in medial compartment load. A study using fluoroscopy during treadmill gait demonstrated articular surface separation at heel strike in 12 of 15 subjects wearing valgus knee braces, with an average change in condylar separation of 1.2 mm and condylar separation angle of 2.2°.[15]

Because valgus bracing results in a valgus moment being applied to the knee joint, in theory the treatment should reduce the varus moment or adduction moment at the knee and, therefore, reduce medial compartment load. The contribution of the brace to the loads at the knee joint has not been documented. The magnitude of the brace moment compared with the load that routinely occurs in the osteoarthritic knee joint is also unknown, as is the effect of increasing the valgus correction in these adjustable braces.

Therefore, the primary objectives of this study were to quantify the valgus moment produced by the brace and to calculate the change in medial compartment load as a result of valgus bracing in the standard clinical brace setting. The secondary objective was to determine the effect of increased valgus alignment of the brace and the effect of increased strap tension on both load sharing by the brace and on medial compartment load at the knee. The final objectives were to document the external and net knee moments in all conditions and to document pain and function in subjects with osteoarthritis before bracing and with routine use of a valgus brace.

MATERIALS AND METHODS

Subjects

Ten men and one woman, with a mean age of 53.2 ± 9.8 years, mean height of 1.79 ± 8.9 meters, and mean body mass of 83.0 ± 6.6 kg were enrolled in the study and underwent pain and activity assessment and gait analysis. Inclusion criteria were a diagnosis of isolated medial compartment osteoarthritis, a neutral or varus (0° to 10°) knee alignment, and no evidence of ligamentous instability. Criteria for exclusion were a history of tibial or femoral fracture, a history of knee surgery other than arthroscopic debridement or meniscectomy, skin or peripheral vascular disease that would prevent brace application, or a fixed flexion contracture. Institutional Review Board approval was obtained for the study, and informed consent was obtained from each participant before testing.

Materials

Custom-manufactured valgus braces (Generation II Unloader ADJ brace, Generation II USA, Inc., Bothell, Washington) were used in the study. The brace is designed to apply a valgus moment about the knee through two mechanisms (Fig. 1). The first is through the angulation of the brace hinge components, which induces a bending moment at the hinge (M_H) when the valgus alignment of the brace is greater than that of the lower limb. The second mechanism for applying a valgus moment is provided by a three-point bending system via the Dynamic Force Strap that spirals around the knee and applies a medially directed force to the lateral aspect of the knee (F_1). The brace incorporates adjustment screws on the hinge just proximal and just distal to the knee joint, which permit the valgus alignment of the brace to be set using a special driver not available to the patient. One full turn of an adjustment screw corresponded to 4° of valgus alignment when the brace was unloaded. Changes in valgus alignment can be made to accommodate patient symptoms of pain. The braces were instrumented with strain gauges on

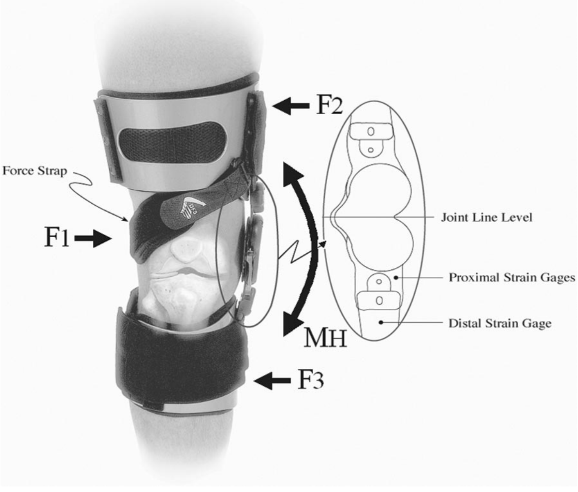

Figure 1. Schematic of the Generation II Unloader brace on a limb with the upper and lower cuff supports and the Dynamic Force Strap. M_H represents the valgus moment contribution due to the hinge. F_1, F_2, and F_3 represent the three-point bending forces generated by the tension in the force trap. The isolated view shows the lower tibial support with a single strain gauge attached at level 1 and two strain gauges attached at level 2.

the medial support bracket to allow determination of the brace loads during walking, and a buckle transducer was used on the force strap to measure strap tension. The force strap, in conjunction with the upper and lower cuffs (F_2 and F_3) which apply laterally directed forces to the thigh and calf, creates three-point bending about the knee joint.

For each subject, a cast of the affected leg, which included the proximal two-thirds of the calf and the distal two-thirds of the thigh, was made by a certified orthotist and shipped to the manufacturer for custom fabrication of the brace. The adjustable braces were set at the factory with a valgus alignment 4° greater than that of the subject's alignment during casting. Two degrees were applied proximal to the knee and 2° distal. In this study, use of the brace with the factory-set alignment and a comfortable strap tension was defined as the "normal" mode of use. On receipt of the brace, the orthotist confirmed proper brace fit and instructed the patient on the application of the brace. Patients were instructed to wear their braces throughout each day and particularly during any physical activities. Each patient used the brace for a minimum of 2 weeks before undergoing gait analysis and completing the visual analog scales.

Brace Instrumentation

The hinge was not amenable to being instrumented at the knee joint line because of a plastic cap and the complex hinge geometry; thus, bending moments were measured at two locations distal to the knee joint line (Fig. 1). The bending moment at the knee joint line was calculated from those two measurements. Two strain gauges (Model #EA-06-062AQ-350; Measurements Group, Inc., Raleigh, North Carolina) were attached to the distal portion of the hinge, and a single strain gauge was attached to the proximal portion of the tibial support. The number and location of the gauges used was determined by the geometry of the hinge and the tibial support. Each patient's brace was instrumented with strain gauges on the day of testing and bench-calibrated just before testing by using known loads. These strain gauges permit determination of the bending moment at each of the two locations distal to the knee. The bending moment at the knee joint line was then extrapolated from the bending moments at these two locations.

The contribution of the force strap to the brace moment at the knee joint line was determined by measuring the strap tension and orientation of the strap as it crossed the knee joint line. The tension in the strap was measured using a buckle transducer (Fig. 2), which was fabricated in-house and calibrated with dead weights before each test. Strap orientation was recorded for each walking trial by using a rigid array with two reflective markers aligned with the strap as it crossed the lateral aspect of the knee joint. This method yielded the magnitude, location, and direction of the strap force vector with respect to the knee joint center. The two components of strap force that contribute to a valgus moment about the knee joint center are the projection of the strap load, which is parallel with the shank segment on the lateral side, and the compressive force through the hinge on the medial side. The strap contribution was then added to the bending moment from the brace hinge to determine the total brace moment about the knee joint center. For the braced conditions, the net moment about the knee was then calculated by subtracting the moment applied by the brace from the external varus moment calculated about the braced knee as a result of the ground reaction force.

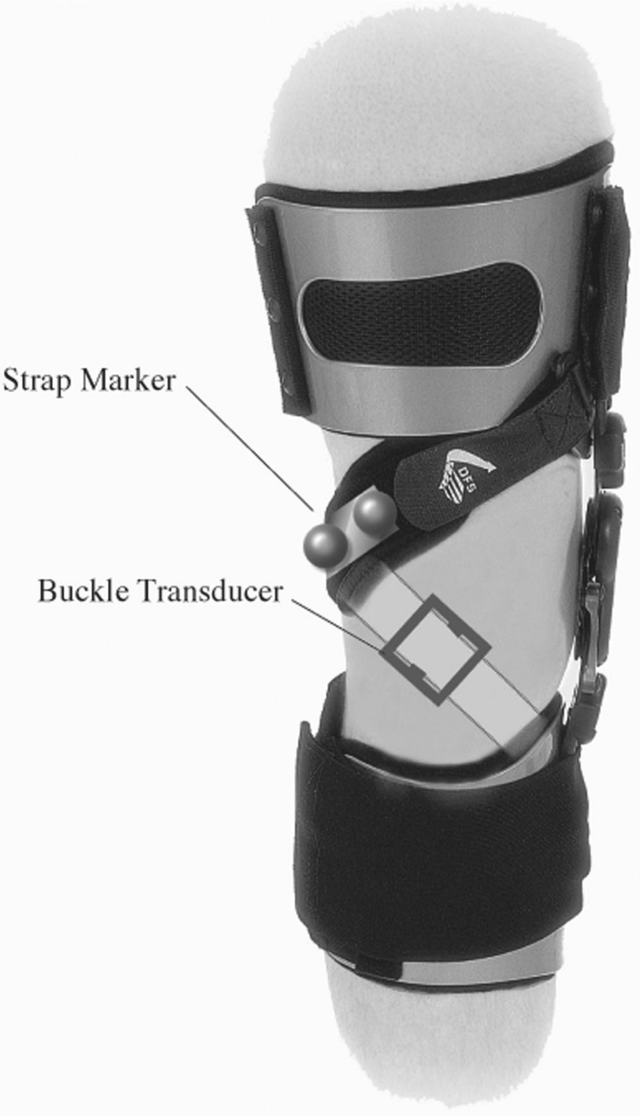

Figure 2. The orientation of the dynamic force strap at the knee joint line was determined by using a marker set that consisted of a pair of reflective markers on a plate. The marker set was aligned with the strap at the lateral aspect of the knee at the level of the joint line.

Gait Measurement

The instrumented brace permitted the measurement of the brace moment at the knee joint line while simultaneously collecting kinematic and kinetic measurements during gait. In addition to the unbraced trials and the normal mode braced trials, three additional conditions were tested. The clinician had the ability to change the valgus alignment of the brace by adjusting the screws at the hinge, and the patient had the ability to adjust the brace by changing the strap tension. Therefore, the effects of increasing these two parameters were investigated to determine whether nominal changes in adjustment produced a measurable effect on load sharing between the brace and the knee. With the braces in their normal mode of use, the subjects self-selected a comfortable strap tension, based on instructions from their fitting orthotist, which was defined as a firm tension without soft tissue binding or pinching. Once it was selected, the strap length in the normal mode was marked so that it could be reproduced.

For the additional three conditions studied, the valgus alignment procedure took advantage of the instrumented brace to align the brace directly to the patient's alignment, instead of being referenced to the cast. With the subject sitting, the force strap loose, and the knee near full extension, the adjustment screws were loosened to completely remove the valgus load from the brace. The screws were then readjusted until the strain gauges showed the first indication that valgus load was being applied. This was considered the 0° valgus setting for the three remaining conditions. At this setting, the brace and knee valgus alignments were matched; that is, there was no valgus load applied by the brace. Two conditions employing a normal strap tension setting, a 4° mode and an 8° mode, were defined, with 4° and 8° of valgus, respectively, added to the 0° baseline. One-half of the adjustment was applied proximally and one-half distally to the knee. The last condition, the "4° tight" mode, was a modification of the 4° mode in which the patient increased the strap tension beyond the normal setting. Tension was increased without limiting knee flexion or extension motion.

Knee kinematics and kinetics were collected using a six-camera video-based, passive marker gait analysis system (Motion Analysis Corporation, Santa Rosa, California) and two force platforms (Bertec Medical, Columbus, Ohio). Reflective markers were placed over anatomic locations on the pelvis and lower extremities to estimate the locations of the hip, knee, and ankle joint centers and subsequently to allow for the computation of joint kinematics during walking. Two force platforms, recording at 1000 Hz and embedded in the center of the walkway, measured the ground reaction forces. Patients were not aware of the force platform locations. An inverse dynamics approach (Orthotrak, Motion Analysis Corporation) was used to calculate the external moments generated about the knee as a result of the ground reaction force in all three planes. Each patient was asked to walk at a self-selected speed wearing the brace and without it. Patients were not coached or instructed on how fast or slow to walk. For kinematic data, three trials were normalized to the entire gait cycle and averaged. Kinetic data were similarly analyzed, but for the stance phase only.

For each patient, the peak external varus moment (M_V) about the knee was calculated during the unbraced condition and in the four braced conditions. In addition, the brace valgus moment (M_B) was also calculated for each of the four braced conditions using the instrumented braces. The net knee moment was calculated for each braced condition, which was essentially the external varus moment minus the brace valgus moment ($M_V - M_B$). Without the use of a valgus brace, the knee would have to counteract the entire external varus moment, so essentially the net knee moment would be equal to the external varus moment. However, with the use of valgus bracing, the net knee moment is reduced with the addition of the opposing valgus moment at the knee of the brace.

Compartment Loads

Medial compartment loads were estimated for the unbraced and braced conditions by using an analytical model. The model factored in the contributions of the ground reaction force, mass moment of inertia of the shank and foot segments, and the brace valgus load. Ligament forces, joint contact points, intercondylar distance, muscle moment arms, and directions of muscle pull were assumed to be constant for the unbraced and braced conditions and between subjects. A schematic of the analytical model is shown in Figure 3. An intercondylar distance of 6 cm was assumed. In this equilibrium model, the external knee flexion moment, M_F, was balanced by the quadriceps force, F_Q, acting with a 4-cm moment arm at the knee joint. An external extension moment was balanced by a hamstring muscle force also acting with a 4-cm moment arm. Quadriceps and hamstring muscle forces contributed in their entirety to the joint compressive force; no adjustment was made for flexion angle. The force along the tibial axis, F_T, was equal to the component of the ground reaction force directed axially through the shank minus the inertial component of the shank and foot segments. This force was computed in Orthotrak as the component of the joint reaction force normal to the tibial plateau that would be present if there were no muscle or ligament forces across the joint.

The external varus moment at the knee joint, M_V, computed in Orthotrak, acted to shift load from the lateral to the medial compartment. It was assumed that neither compartment was distracted such that collateral ligament forces were not significant and that cruciate ligament forces were the same across all conditions. Shear forces at the knee joint were assumed to pass through the points of contact in the compartments so that they did not contribute to the moments about the knee. The brace applied an external valgus moment, M_B, that acted to shift load from the medial to the lateral compartment. Thus, we estimated the compartment loads by using the kinematic and kinetic gait analysis data and the measured brace moments. Each subject served as his or her own control when the change in medial compartment loads between the unbraced and braced trials was assessed.

Pain and Activity Assessment

Pain and activity levels were assessed using a 100-mm visual analog scale[11] anchored at each end with terms

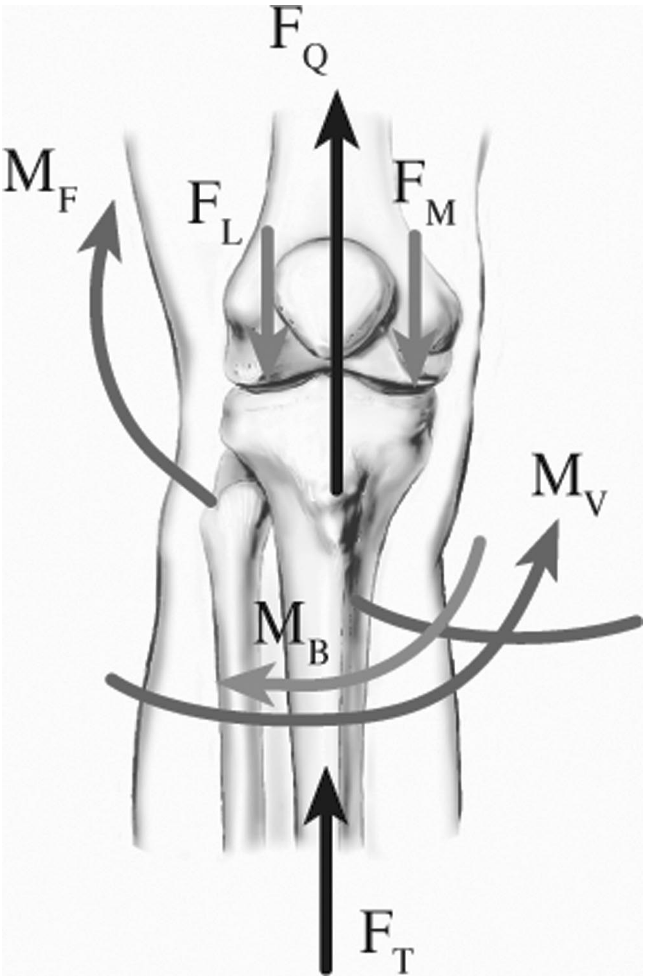

Figure 3. Diagram of the analytical model used to estimate medial compartment force. F_T depicts the component of the ground reaction force directed axially through the tibia. M_F depicts the external flexion moment and F_Q the quadriceps muscle force required to counteract the external flexion moment. F_M and F_L represent the medial and lateral compartment forces, respectively. M_V represents the external varus moment arising from the ground reaction force and M_B the valgus moment generated by the brace.

describing the amount of pain felt: "no pain" to "worst pain possible." The subject made a mark on the line corresponding to the amount of pain felt, and the distance from the "no pain" end of the scale to the marker was measured in millimeters. The same scale was used for an activity level scale ranging from 0% on the left anchor to 100% on the right anchor. A 0% choice indicated complete limitation in performing usual daily activities and 100% indicated no limitation in performing usual daily activities. The scales were completed at the time of gait testing and after the patient had worn the brace for 2 weeks to obtain scores for both the prebracing condition and for the normal mode braced condition.

Statistical Analysis

Repeated-measures analysis of variance with post hoc testing was used to confirm that walking speed was not different across conditions and to assess differences in moments and loads among all conditions, including the additionally corrected settings. All repeated-measures analyses of variance were corrected for multiple measures. Scores for pain and activity level were analyzed using the Mann-Whitney test. Alpha was set at 0.05 for all statistical tests.

RESULTS

Walking Speed

Walking speed remained constant regardless of condition. There was no difference between the unbraced condition and the normal mode of use (132 ± 10 cm/sec and 128 ± 10 cm/sec, respectively). The average walking speeds with the brace in the 4°, 8°, and 4° tight modes were 128 ± 8 cm/sec, 130 ± 9 cm/sec, and 129 ± 9 cm/sec, respectively. No significant difference in self-selected walking speeds existed among the conditions.

Brace Valgus Moment (M_B)

Brace valgus moment (M_B) averaged from a minimum of 5.9 N·m for the normal mode of brace use to a maximum of 11.0 N·m for the 8° mode (Table 1). The brace valgus moment was not different for the normal mode of use and the 4° setting. Application of additional valgus correction either by increasing the valgus angle (8°) or increasing the strap tension (4° tight) resulted in a significantly greater brace valgus moment.

Medial Compartment Load

There was a significant reduction in the average medial compartment load for the normal mode of use condition compared with the unbraced condition (Table 2). Increasing the brace valgus angulation from 4° to 8° had a significant effect on reducing the medial compartment load. However, increasing the strap tension in the 4° condition did not have an effect on the medial compartment load. Additionally, the 4° mode, 8° mode, and the 4° tight mode all demonstrated significant decreases in the medial compartment load when compared with the unbraced condi-

TABLE 1
Comparisons of Average Brace Valgus Moments

Brace mode comparisons	Brace valgus moment (N·m)	Difference (N·m)	% change	Significance
Normal vs. 4°	5.9 ± 3.1 7.6 ± 3.4	1.7	29	No significance
4° vs. 8°	7.6 ± 3.4 11.0 ± 2.8	3.4	45	*P* = 0.0009
4° vs. 4° tight	7.6 ± 3.4 10.1 ± 3.3	2.5	33	*P* = 0.015

TABLE 2
Difference in Average Medial Compartment Load between the Different Brace Conditions

Brace mode comparisons	Compartment load (N)	Difference (N)	% change	Significance
Unbraced vs. normal	1048 ± 277 964 ± 274	−84	−8	$P = 0.039$
4° vs. 8°	934 ± 258 869 ± 234	−65	−7	$P = 0.025$
4° vs. 4° tight	934 ± 258 896 ± 257	−38	−4	No significance
Additional comparisons with the unbraced condition				
Unbraced vs. 4°	1048 ± 277 934 ± 258	−114	−11	$P = 0.006$
Unbraced vs. 8°	1048 ± 277 869 ± 234	−179	−17	$P = 0.0007$
Unbraced vs. 4° tight	1048 ± 277 896 ± 257	−152	−15	$P = 0.0009$

tion. The greatest reduction, of 179 N, was seen when comparing the 8° mode with the unbraced condition.

Maximum Net Knee Moment ($M_V - M_B$)

The maximum net knee moment was not different for the unbraced and normal mode of bracing (Table 3); however, when valgus angulation was increased from 4° to 8°, a significant reduction in maximum net knee moment was observed. Increasing the strap tension in the 4° mode did not have a significant effect on the maximum net knee moment. However, when compared with the unbraced condition, the 4° and 8° modes, as well as the increased strap tension mode, resulted in a significant decrease in the maximum net knee moment.

External Varus Knee Moment (M_V)

The maximum external varus knee moment was not different for the unbraced and normal mode of use conditions, and averaged 55.3 ± 18.6 N·m and 54.8 ± 17.7 N·m, respectively. There was no difference in the external varus knee moments for any of the conditions. The maximal external knee varus moments for the remaining conditions were 52.6 ± 17.9 N·m (4°), 51.7 ± 16.9 N·m (8°), and 51.1 ± 16.9 N·m (4° tight).

Pain and Function (Visual Analog Scale)

The mean scores before bracing and with bracing in the normal mode are listed in Table 4. No pain and activity assessment was performed in any of the other braced conditions. Using the Mann-Whitney test, both the pain and activity level scores demonstrated significant improvements between the prebracing condition and the normal bracing mode condition.

DISCUSSION

Valgus bracing is designed to reduce the load on the medial compartment through the application of an external valgus moment about the knee joint. This external valgus moment in turn reduces the varus or adduction moment responsible for excessive compartment loading seen in medial tibiofemoral osteoarthritis. Studies of the clinical efficacy of valgus bracing have shown significant pain relief and improvement in function using a number of

TABLE 3
Changes in Maximum Net Knee Moment between the Different Brace Conditions

Brace mode comparisons	Net knee moment (N·m)	Difference (N·m)	% change	Significance
Unbraced vs. normal	55.3 ± 18.6 52.2 ± 16.3	3.1	6	No significance
4° vs. 8°	48.1 ± 17.2 44.2 ± 15.7	3.9	8	$P = 0.004$
4° vs. 4° tight	48.1 ± 17.2 44.7 ± 17.5	3.4	7	No significance
Additional comparisons with the unbraced condition				
Unbraced vs. 4°	55.3 ± 18.6 48.1 ± 17.2	7.1	13	$P = 0.004$
Unbraced vs. 8°	55.3 ± 18.6 44.2 ± 15.7	11.1	20	$P = 0.0008$
Unbraced vs. 4° tight	55.3 ± 18.6 44.7 ± 17.5	10.6	19	$P = 0.001$

TABLE 4
Visual Analog Scores before and after Knee Bracing

Scale[a]	Before bracing	After bracing in normal mode	Significance
Pain (mm)	7.9 ± 2.2	4.4 ± 2.7	$P = 0.0012$
Activity level (%)	36 ± 26	61 ± 23	$P = 0.0010$

[a] Pain was measured along a 100-mm line from no pain (0) to worst pain possible (100). Activity level was measured as percentage along the line, with 0% being complete limitation of activities of daily living and 100% as no limitation.

validated test methods.[8–10,13,14,17,18,20] However, most investigators have only either examined the clinical effects of bracing[10,14,18] or the effects of bracing on gait parameters.[3,8,17,20–22]

The present study examined in detail the biomechanical effects of valgus bracing on the knees of patients with osteoarthritis. The effects that valgus bracing has on both gait and on load sharing during level walking were investigated. The brace instrumentation allowed the determination of the load applied by the brace across the knee to unload the affected compartment. In addition, compartment loads were also estimated using the gait data, instrumented brace data, and a generic analytical knee model.

In one previous study, researchers analyzed the effect of valgus bracing in vivo using fluoroscopy during a treadmill gait.[15] This study demonstrated an average change in condylar separation angle of 2.2° and an average change in condylar separation of 1.2 mm at heel strike.[15] Three of the subjects who were overweight and considered to have suboptimal brace fixation demonstrated no change in condylar separation.

In another study of 11 patients with medial gonarthrosis who were treated with custom valgus bracing and who underwent gait analysis, investigators reported a 10% decrease in the mean adduction (varus) moment at the knee.[17] The authors suggested that the benefits of these braces occurred as a result of an altered gait pattern, which included a reduced varus thrust (or external varus moment). However, only the external adduction moment at the knee was reported, and the authors did not determine the contribution of the brace to the varus moment about the knee. Furthermore, the study did not take into consideration the contribution of altered knee extensor and flexor moments, which affect the compartment loads at the knee. Although the extension and flexion moments for the group were dismissed as not being significantly different when wearing the brace, their effects on an individual basis need to be considered, as do the individual brace contributions to medial compartment force.

In our group of patients, we also saw a trend toward reduction in the external knee varus moment (or varus thrust), as was seen in previous studies. However, when we took into account the counteracting brace valgus moment, the net knee moment was significantly reduced when most of the brace modes were compared with the unbraced knee. This result shows that the brace shares a portion of the external varus load with the knee, which in turn reduces medial compartment load. With the brace in the normal mode, the net knee moment was not significantly different for the unbraced knee, even though it was reduced by 6%. But the net knee moment was decreased by as much as 20% in the 8° mode, which was significant. This reduction in the net knee moment with the valgus brace also significantly affected medial compartment loads. In the normal mode the medial compartment force was significantly reduced by 8%, and in the 8° mode, the medial compartment load was reduced on average by 179 N, or 17%. Therefore, one of the possible reasons why patients experience symptomatic pain relief with valgus bracing is as a result of reduced load on the affected compartment.

Investigation of the effects of increased hinge angulation and strap tension revealed results that may alter the fitting process of these braces. The normal mode that the braces are placed into by the orthotist did not significantly decrease the net knee moment and also had the lowest percentage reduction in the medial compartment load. The normal mode is intended to be aligned in 4° of valgus relative to each subject's alignment. However, when we placed the braces into our 4° mode relative to the instrumented zero baseline, we found significant reductions in the net knee moment and greater reduction in the medial compartment load.

When we investigated the increased valgus alignment with the 8° mode compared with the 4° mode, we found that the brace moment significantly increased and the net knee moment and medial compartment load decreased. Thus, the greater the amount of valgus correction incorporated into the brace, the greater the amount of unloading of the affected compartment that was achieved. We were concerned that shifting the load from the medial compartment to the lateral compartment might be injurious. In this population of patients, the small increase in the lateral compartment load was not significant and likely remains at a physiologic level similar to that before onset of the arthritic condition.

Increasing the strap tension did not have as great an effect as increasing the valgus angulation. The brace moment did significantly increase in the 4° tight mode as compared with the 4° mode, but increasing the strap tension reduced neither the net knee moment nor the medial compartment load. We believe that this phenomenon is partly a result of the coupling of the Dynamic Force Strap and the hinge. As the strap becomes tighter, the load on the brace from the strap becomes greater, which in turn tends to reduce the contribution of the brace hinge. Therefore, the optimization between strap tension and valgus angulation needs to be investigated further.

We also measured the alterations in pain and activity level resulting from valgus bracing. The visual analog scales demonstrated significant relief of pain and improvement in function with valgus bracing for the 11 subjects. The scores illustrated the clinical benefits of valgus bracing for this group and were consistent with the results of other studies.[8–10,14,18] A limitation of this study was that the prebrace scale was completed after use of the brace; this scale was completed retrospectively based on the subject's ability to recall their prebrace status. The effect of this limitation is difficult to assess, as the patients were able to visualize both scales simultaneously and score their prebrace scale relative to scoring of their current postbrace condition.

In conclusion, this study, in addition to providing a clinical assessment of patient outcomes, has provided insight into the biomechanical mechanism associated with valgus bracing. Previous studies have not quantified the varus load taken up by the brace or its effect on compartment load. In this study, we have documented those loads and determined, with use of an analytical model and measured kinematics and kinetics, the change in medial compartment load that occurs with bracing. The data support the theory that valgus bracing can significantly reduce medial compartment loads, which is consistent with patient reports regarding pain relief and improved function with the use of valgus bracing. Therefore, valgus bracing with adjustable alignment remains an effective therapeutic treatment modality for reducing pain and increasing function in patients with medial tibiofemoral osteoarthritis of the knee.

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REFERENCES

1. Ahlback S: Osteoarthrosis of the knee: A radiographic investigation. *Acta Radiol Diagn (Stockh) Suppl 277:* 7–72, 1968
2. Barrett DS, Cobb AG, Bentley G: Joint proprioception in normal, osteoarthritic and replaced knees. *J Bone Joint Surg 73B:* 53–56, 1991
3. Draper ERC, Cable JM, Sanchez-Ballester J, et al: Improvement in function after valgus bracing of the knee. *J Bone Joint Surg 82B:* 1001–1005, 2000
4. Felson DT, Lawrence RC, Dieppe PA, et al: Osteoarthritis: New insights. Part 1: The disease and its risk factors. *Ann Intern Med 133:* 635–646, 2000
5. Felson DT, Radin EL: What causes knee osteoarthritis: Are different compartments susceptible to different risk factors? *J Rheumatol 21:* 181–183, 1994
6. Harrington IJ: Static and dynamic loading patterns in knee joints with deformities. *J Bone Joint Surg 65A:* 247–259, 1983
7. Hernborg JS, Nilsson BE: The natural course of untreated osteoarthritis of the knee. *Clin Orthop 123:* 130–137, 1977
8. Hewett TE, Noyes FR, Barber-Westin SD, et al: Decrease in knee joint pain and increase in function in patients with medial compartment arthrosis: A prospective analysis of valgus bracing. *Orthopedics 21:* 131–138, 1998
9. Hillstrom HJ, Brower DJ, Bhimji S, et al: Assessment of conservative realignment for the treatment of varus knee osteoarthritis: Biomechanics and joint pathophysiology. *Gait Posture 11:* 170–171, 2000
10. Horlick SG, Loomer RL: Valgus knee bracing for medial gonarthrosis. *Clin J Sport Med 3:* 251–255, 1993
11. Huskisson EC: Visual analog scales, in Melzack R (ed): *Pain Measurement and Assessment.* New York, Raven Press, 1983, pp 33–37
12. Johnson F, Leitl S, Waugh W: The distribution of load across the knee: A comparison of static and dynamic measurements. *J Bone Joint Surg 62B:* 346–349, 1980
13. Katsuragawa Y, Fukui N, Nakamura K: Change of bone mineral density with valgus knee bracing. *Int Orthop 23:* 164–167, 1999
14. Kirkley A, Webster-Bogaert S, Litchfield R, et al: The effect of bracing on varus gonarthrosis. *J Bone Joint Surg 81A:* 539–548, 1999
15. Komistek RD, Dennis DA, Northcut EJ, et al: An in vivo analysis of the effectiveness of the osteoarthritic knee brace during heel-strike of gait. *J Arthroplasty 14:* 738–742, 1999
16. Lawrence RC, Helmick CG, Arnett FC, et al: Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States. *Arthritis Rheum 41:* 778–799, 1998
17. Lindenfeld TN, Hewett TE, Andriacchi TP: Joint loading with valgus bracing in patients with varus gonarthrosis. *Clin Orthop 344:* 290–297, 1997
18. Matsuno H, Kadowaki KM, Tsuji H: Generation II knee bracing for severe medial compartment osteoarthritis of the knee. *Arch Phys Med Rehabil 78:* 745–749, 1997
19. Noyes FR, Schipplein OD, Andriacchi TP, et al: The anterior cruciate ligament-deficient knee with varus alignment: An analysis of gait adaptations and dynamic joint loadings. *Am J Sports Med 20:* 707–716, 1992
20. Otis JC, Backus SI, Campbell DA, et al: Valgus bracing for knee osteoarthritis: A biomechanical and clinical outcome study. *Gait Posture 11:* 116–117, 2000
21. Pollo FE, Otis JC, Wickiewicz TL, et al: Biomechanical analysis of valgus bracing for the osteoarthritic knee. *Arthritis Rheum 38:* S241, 1995
22. Self BP, Greenwald RM, Pflaster DS: A biomechanical analysis of a medial unloading brace for osteoarthritis of the knee. *Arthritis Care Res 13:* 191–197, 2000
23. Wang JW, Kuo KN, Andriacchi TP, et al: The influence of walking mechanics and time on the results of proximal tibial osteotomy. *J Bone Joint Surg 72A:* 905–909, 1990
24. Winter DA, Robertson DGE: Joint torque and energy patterns in normal gait. *Biol Cybern 29:* 137–142, 1978