TITLE: The Mechanical Effects of a Knee Support Garment during Running

***Running Head*:** Knee Unloading during Running

ABSTRACT

The major aim of the present study was twofold: first, to determine if the Opedix knee support garment enhances frontal plane knee alignment during running; and second to determine if this garment also reduces the knee adduction moment indicating a load reduction to the medial knee compartment. We hypothesized that compared to running with a control garment the Opedix knee support garment would reduce knee adduction range of motion (ROM) and the peak knee adduction moment. Ten recreational runners performed over-ground running with an Opedix knee support garment and a control garment. Three-dimensional, lower extremity kinematics and ground reaction forces were collected. Knee adduction ROM and the peak knee adduction moment were compared between conditions. Gait velocity was equal between conditions ($p>0.05$). Compared to running with the control garment, the Opedix knee support garment reduced knee adduction ROM by 26% and the peak knee adduction moment by 16% (both $p<0.05$). The reductions in the peak knee adduction moment were related to reductions in the moment arm distance between the knee joint center and the resultant ground reaction force. The 16% reduction in the peak knee adduction moment suggests the Opedix knee support system reduced a significant portion of the varus load that would normally be sustained by the knee joint and the soft tissues. Running with the Opedix knee support garment may decrease knee joint loading and serve as a viable preventative tool to slow the rate of knee degeneration after long-term use.

Key words: Biomechanics, compression garment, knee adduction moment, unloading

INTRODUCTION

During gait a disproportionate medial transmission of load results from a stance-phase knee adduction moment tending to bend the knee inward [1]. The peak knee adduction moment reflects the magnitude of intrinsic compressive load on the medial knee compartment and its progressive degeneration [2-4]. Participation in weight bearing exercise involving repeated exposure to significant joint loading has been shown to increase the risk for knee degeneration [5-7].

Although athletic compression garments and their use in sport and exercise have increased exponentially, no evidence-based research has asserted that these garments mechanically support the knee joint and decrease joint loading during athletic activity. However, a new biomechanical compression garment from Opedix (Alignmed LLC, Santa Ana, CA) incorporates a knee support system designed to resist the outward motion of the knee thereby promoting knee alignment and reducing medial knee compartment loading during sports and exercise.

The purpose of this study was to determine if the Opedix knee support garment enhances frontal plane knee alignment and reduces knee joint loading during running. We hypothesized that compared to running with a control garment the Opedix knee support garment would reduce knee adduction range of motion (ROM) and the peak knee adduction moment.

METHODS

Five male (25.00 ± 1.38 y; 1.60 ± 0.02 m; 834.74 ± 43.4 N) and five female (22.60 ± 0.81 y; 1.47 ± 0.02 m; 572.99 ± 27.51 N) recreational runners participated in this study. All participants provided written consent prior to participation, in accordance with the Institutional Review Board.

The knee support garment (R1 Opedix running tights, Alignmed LLC, Santa Ana, CA) used in this study is very different from traditional spandex or Lycra compression tights (Figure 1). The Opedix (OPX) knee support garment incorporates an anchor and sling design to resist knee adduction, promote lower extremity alignment and decrease medial knee compartment loading. The OPX knee support garment runs from the individual's waist to just above the maleoli and has non-stretch banding around the knee for joint stability and a four-way stretch fabric to compress and support the lower extremity muscles.

-Figure 1 about here-

Testing utilized the OPX knee support garment and a compression short (TYR Sport, Inc., Huntington Beach, CA) as the control garment (CON). The CON garment (80% nylon, 20% Lycra) runs from the waist to just above the knee. The experimental protocol consisted of over-ground running on a 15 m walkway at a stride frequency of 90 beats per minute with either the OPX knee support or CON garment. After completing one garment condition, the participant rested for approximately 15 minutes and then performed the second condition. The order of testing was balanced such that 5 of the participants started the testing protocol with the OPX knee support garment and 5 with the CON garment. Prior to the first gait test, the participant was fitted with a standardized shoe (Turntec, model # TM08061) and allowed to familiarize themselves with the testing procedures. Each participant practiced running on the walkway until they demonstrated consistent foot strikes on the force platform. Ten running trials where full foot placement was achieved on the force platform were analyzed for each garment condition.

Fifty-three retro-reflective, spherical markers (diameter =1.0 to 2.6 cm) were attached to select anatomical landmarks to define a rigid-link model of the body. An orthopaedic surgeon (BS) placed the markers on all subjects throughout the testing protocol. Only the markers on the thigh and shank were removed and then re-attached between conditions. A ten-camera motion analysis system (Motion Analysis, Santa Rosa, CA, USA) was used to capture three dimensional gait motions at a frequency of 120 Hz. The marker trajectories were low pass filtered at 10 Hz with a fourth order Butterworth filter. Ground reaction forces were collected (1200 Hz) with a force plate (Bertec Corp., Columbus, Ohio) that was mounted flush with the surface of the walkway.

Hip, knee and ankle kinematics were calculated with a commercial software package (Motion Monitor, Innovative Sports Training, Chicago, IL, USA). Angles were determined using an YXZ sequence as proposed by Grood and Suntay [8] such that sagittal joint motion was represented as rotations about the y-axis, frontal plane motion represented by rotations about the x-axis and transverse plane motion as rotations about the z-axis. For each condition, a static, anatomical trial was used to subtract the baseline kinematic positions to compensate for potential marker placement errors.

The external knee adduction moment was calculated as the moment produced by the component of the ground reaction force in the frontal plane acting about the geometric center of the knee [9]. The calculation is a product of the net force in the frontal plane (vector addition of the vertical and medial-lateral ground reaction forces) and the straight line distance from the knee joint center to this net force (moment arm). This variable represents the magnitude of medial knee compartment loading but does not account for the ligament and muscle force contributions. However, medial knee compartment loading is predominantly determined (≈85%) by the orientation of the ground reaction force because this force passes medial to the knee during gait [9].

Descriptive statistics were calculated for gait speed; peak vertical, anterior, posterior and lateral ground reaction forces; sagittal and frontal plane hip, knee and ankle range of motion (ROM); and the external knee adduction moment. Parametric statistics were implemented to compare the effects of the OPX knee support and CON garments on gait speed, knee adduction ROM and the peak external knee adduction moment. The components of the peak external knee adduction moment, including the net medial-lateral ground reaction force and the moment arm distance between the knee joint center and the net medial-lateral ground reaction force vector, were also compared between gait conditions. These variables were contrasted with paired t-tests at an alpha level of p=0.05. All data are present as the mean ± standard error.

RESULTS

Running speed was not different between the CON and OPX conditions (CON: 3.17 ± 0.11 m/s; OPX: 3.20 ± 0.11 m/s) (t(9)= 0.015, p=0.987).

The mean (± standard error) sagittal and frontal plane angular position-time histories for the hip, knee and ankle during the OPX knee support and CON garment conditions are graphically illustrated in Figure 2. On average, the mean (± standard errors) sagittal and frontal plane hip, knee and ankle ROMs did not differ by more than 3° between gait conditions. The mean knee adduction ROM was on average 26% lower during the OPX knee support garment condition (CON: 5.03 ± 0.49°; OPX: 3.69 ± 0.45°) (t(9)= 4.06, p=0.003).

-Figure 2 about here-

The mean (± standard error) external knee adduction moment-time history during the OPX knee support and CON garment conditions are graphically illustrated in Figure 3. The peak external knee adduction moment was on average 16% lower during the OPX knee support garment condition compared to the CON garment condition (CON: -90.18 ± 9.99 Nm; OPX: -75.73 ± 6.39 Nm) (t(9)= 3.14, p=0.012). The peak net medial-lateral forces were statistically similar between gait conditions (CON: 1613.24 ± 137.86 N; OPX: 1601.95 ± 137.76 N) (t(9)= 0.520, p=0.616), but the peak moment arm lengths were on average 13% shorter during the OPX knee support garment condition (CON: -0.056 ± 0.003 m; OPX: -0.048 ± 0.004 m) (t(9)= 3.31, p=0.009). Further analysis revealed that the within-subject reductions in the peak knee adduction moment between gait conditions were positively related to the within-subject reductions in the peak moment arm distances (r=0.91, $p<0.05$).

-Figure 3 about here-

DISCUSSION

The results of this study support the hypothesis that the Opedix knee support garment mechanically reduces knee adduction and the peak knee adduction moment during running. Researchers have demonstrated that the peak knee adduction moment is related to medial knee compartment loading and it's degeneration [10, 11]. This is the first study to show that a compression garment with a biomechanical knee support system can reduce medial knee compartment loading during running. The accumulative effects of this load reduction during every foot-ground impact may have long-term, functional significance to the millions of competitive and recreational runners.

Participation in weight bearing exercise involving repeated exposure to significant joint loading has been shown to increase the risk for knee degeneration [5-7]. A predominant risk factor for the progression of medial knee compartment degeneration during weight bearing exercise is the dynamic bowing-out of the knee laterally or knee adduction [12]. Neutrally aligned knees during static measurement demonstrate knee adduction while the limb is bearing weight during the stance phase of gait. This dynamic knee adduction on average reaches a maximum of 3° during walking [13] but is accentuated during running and reaches up to 6° [14]. In agreement with these researchers, the runners in the current study demonstrated a maximum near 5° of knee adduction during the CON garment condition and this was reduced by 26% when running with the Opedix knee support garment. Medial knee compartment loading is enhanced with greater values of knee adduction [12] thus mechanical interventions that reduce dynamic knee adduction during gait may have strong potential to reduce the rate or progression of knee degeneration.

Shelburne et al. [1] calculated that over 80% of the tibio-femoral load is distributed to the medial knee compartment during the stance phase of walking. The higher load on the medial knee compartment is due to the knee adduction moment, which is the torque generated from the resultant ground reaction force that passes medial to the knee joint. This moment promotes knee adduction and, in part, explains why degeneration is more prevalent in the medial knee compartment than in the lateral compartment [15]. Conservative interventions aimed at reducing the rate or progression of knee degeneration attempt to unload the medial knee compartment [16-18]. These mechanical interventions have been shown to reduce the peak knee adduction moment from 2 to 36%. The 16% reduction in this variable found in the current study is similar to these authors and suggests the Opedix knee support system reduced a significant portion of the varus load that would normally be sustained by the knee joint and the soft tissues during running.

The mechanical basis for reducing the knee adduction moment is different for footwear interventions and valgus-producing knee braces. Footwear interventions are designed to cause a lateral shift in the location of the center of pressure where the ground reaction forces are imparted onto the foot [18, 19]. A lateral shift in the center of pressure moves the net medial-lateral ground reaction force vector closer to the knee joint center thereby reducing the moment arm distance and the knee adduction moment. Valgus-producing knee braces adjust limb alignment by directly placing a knee abduction moment on the limb to reduce the net knee adduction moment. Similar to valgus-producing knee braces, the Opedix knee support system is designed to resist knee adduction during weight bearing activities by providing a progressive knee abduction moment as the knee moves laterally. A reduction in knee adduction during gait allows the knee joint center to remain closer to the net medial-lateral ground reaction force vector and thus decrease the moment arm distance and the knee adduction moment.

Increased proprioception (joint position awareness) or kinesthesia (joint movement awareness) may have also played a role in reducing the peak knee adduction moment when running with the Opedix knee support garment. Perceptual improvements in position and movement awareness have been found for individuals wearing elastic bandages or neoprene sleeves during passive or active movement tasks [20, 21]. Reduced proprioception or kinesthesia can predispose the knee joint to abnormal kinematics that when combined with an increased knee adduction moment [11] may shift more load to the medial compartment and facilitate the progression of joint degeneration. The muscular compression produced by the Opedix knee support garment may have produced sensory stimuli similar to the levels noted for elastic bandages or neoprene sleeves. However, neither proprioception nor kinesethesia were measured in the current study and future studies are recommended to determine the role that these factors might contribute to improvements in knee alignment and medial joint loading while running with the Opedix knee support garment.

CONCLUSION

This study measured the immediate effects of running with, compared to without, the Opedix knee support garment and found reduced knee adduction range of motion and the peak knee adduction moment. The 16% reduction in the peak knee adduction moment was found to be related to a smaller moment arm distance between the knee joint center and the net frontal plane ground reaction force vector. The results indicate that the Opedix knee support garment decreases knee joint loading during running and with long-term use may serve as a viable preventative tool to slow the rate of knee degeneration.

PRACTICAL IMPLICATIONS

- Medial knee compartment loading and its degeneration is related to the peak knee adduction moment during gait.
- This study found the peak knee adduction moment to be reduced by 16% when running with a knee support garment compared to a control garment.
- Mechanical load reductions during every foot-ground impact may accumulate over time and slow the rate of clinical issues involving the knee joint.

ACKNOWLEDGEMENTS

This study was funded by Alignmed LLC and the Steadman Philippon Research Institute. The Steadman Philippon Research Institute is a 501(c)3 non-profit institution supported financially by private donations and corporate support from the following entities: Smith & Nephew Endoscopy, Arthrex, Siemens Medical Solutions USA, Saucony, OrthoRehab, Ossur Americas and Alignmed LLC. One or more of the authors receives royalties from the commercial entity of Alignmed LLC.

REFERENCES

1. Shelburne, K.B., M.R. Torry, J.R. Steadman, et al., Effects of foot orthoses and valgus bracing on the knee adduction moment and medial joint load during gait. *Clin Biomech (Bristol, Avon)*, 2008. **23**(6): p. 814-21.
2. Baliunas, A.J., D.E. Hurwitz, A.B. Ryals, et al., Increased knee joint loads during walking are present in subjects with knee osteoarthritis. *Osteoarthritis Cartilage*, 2002. **10**(7): p. 573-9.
3. Miyazaki, T., M. Wada, H. Kawahara, et al., Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. *Ann Rheum Dis*, 2002. **61**(7): p. 617-22.
4. Sharma, L., D.E. Hurwitz, E.J. Thonar, et al., Knee adduction moment, serum hyaluronan level, and disease severity in medial tibiofemoral osteoarthritis. *Arthritis Rheum*, 1998. **41**(7): p. 1233-40.
5. Jackson, B.D., A.E. Wluka, A.J. Teichtahl, et al., Reviewing knee osteoarthritis--a biomechanical perspective. *J Sci Med Sport*, 2004. **7**(3): p. 347-57.
6. Kujala, U.M., J. Kettunen, H. Paananen, et al., Knee osteoarthritis in former runners, soccer players, weight lifters, and shooters. *Arthritis Rheum*, 1995. **38**(4): p. 539-46.
7. Spector, T.D., P.A. Harris, D.J. Hart, et al., Risk of osteoarthritis associated with long-term weight-bearing sports: a radiologic survey of the hips and knees in female ex-athletes and population controls. *Arthritis Rheum*, 1996. **39**(6): p. 988-95.
8. Grood, E.S. and W.J. Suntay, A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *J Biomech Eng*, 1983. **105**(2): p. 136-44.
9. Shelburne, K.B., M.R. Torry, and M.G. Pandy, Contributions of muscles, ligaments, and the ground-reaction force to tibiofemoral joint loading during normal gait. *J Orthop Res*, 2006. **24**(10): p. 1983-90.
10. Pollo, F.E., J.C. Otis, S.I. Backus, et al., Reduction of medial compartment loads with valgus bracing of the osteoarthritic knee. *Am J Sports Med*, 2002. **30**(3): p. 414-21.
11. Schipplein, O.D. and T.P. Andriacchi, Interaction between active and passive knee stabilizers during level walking. *J Orthop Res*, 1991. **9**(1): p. 113-9.
12. Chang, A., K. Hayes, D. Dunlop, et al., Thrust during ambulation and the progression of knee osteoarthritis. *Arthritis Rheum*, 2004. **50**(12): p. 3897-903.
13. Barrios, J.A., I.S. Davis, J.S. Higginson, et al., Lower extremity walking mechanics of young individuals with asymptomatic varus knee alignment. *J Orthop Res*, 2009. **27**(11): p. 1414-9.
14. Williams, D.S., 3rd, I. McClay Davis, and S.P. Baitch, Effect of inverted orthoses on lower-extremity mechanics in runners. *Med Sci Sports Exerc*, 2003. **35**(12): p. 2060-8.
15. Felson, D.T. and E.L. Radin, What causes knee osteoarthrosis: are different compartments susceptible to different risk factors? *J Rheumatol*, 1994. **21**(2): p. 181-3.
16. Erhart, J.C., A. Mundermann, B. Elspas, et al., A variable-stiffness shoe lowers the knee adduction moment in subjects with symptoms of medial compartment knee osteoarthritis. *J Biomech*, 2008. **41**(12): p. 2720-5.
17. Fantini Pagani, C.H., W. Potthast, and G.P. Bruggemann, The effect of valgus bracing on the knee adduction moment during gait and running in male subjects with varus alignment. *Clin Biomech (Bristol, Avon)*. **25**(1): p. 70-6.

18. Kerrigan, D.C., J.L. Lelas, J. Goggins, et al., Effectiveness of a lateral-wedge insole on knee varus torque in patients with knee osteoarthritis. *Arch Phys Med Rehabil*, 2002. **83**(7): p. 889-93.
19. Kakihana, W., M. Akai, K. Nakazawa, et al., Effects of laterally wedged insoles on knee and subtalar joint moments. *Arch Phys Med Rehabil*, 2005. **86**(7): p. 1465-71.
20. Khabie, V., M.C. Schwartz, A.S. Rokito, et al., The effect of intraarticular anesthesia and elastic bandage on elbow proprioception. *J Shoulder Elbow Surg*, 1998. **7**(5): p. 501-4.
21. Perlau, R., C. Frank, and G. Fick, The effect of elastic bandages on human knee proprioception in the uninjured population. *Am J Sports Med*, 1995. **23**(2): p. 251-5.

FIGURES

Figure 1.

Figure 2.

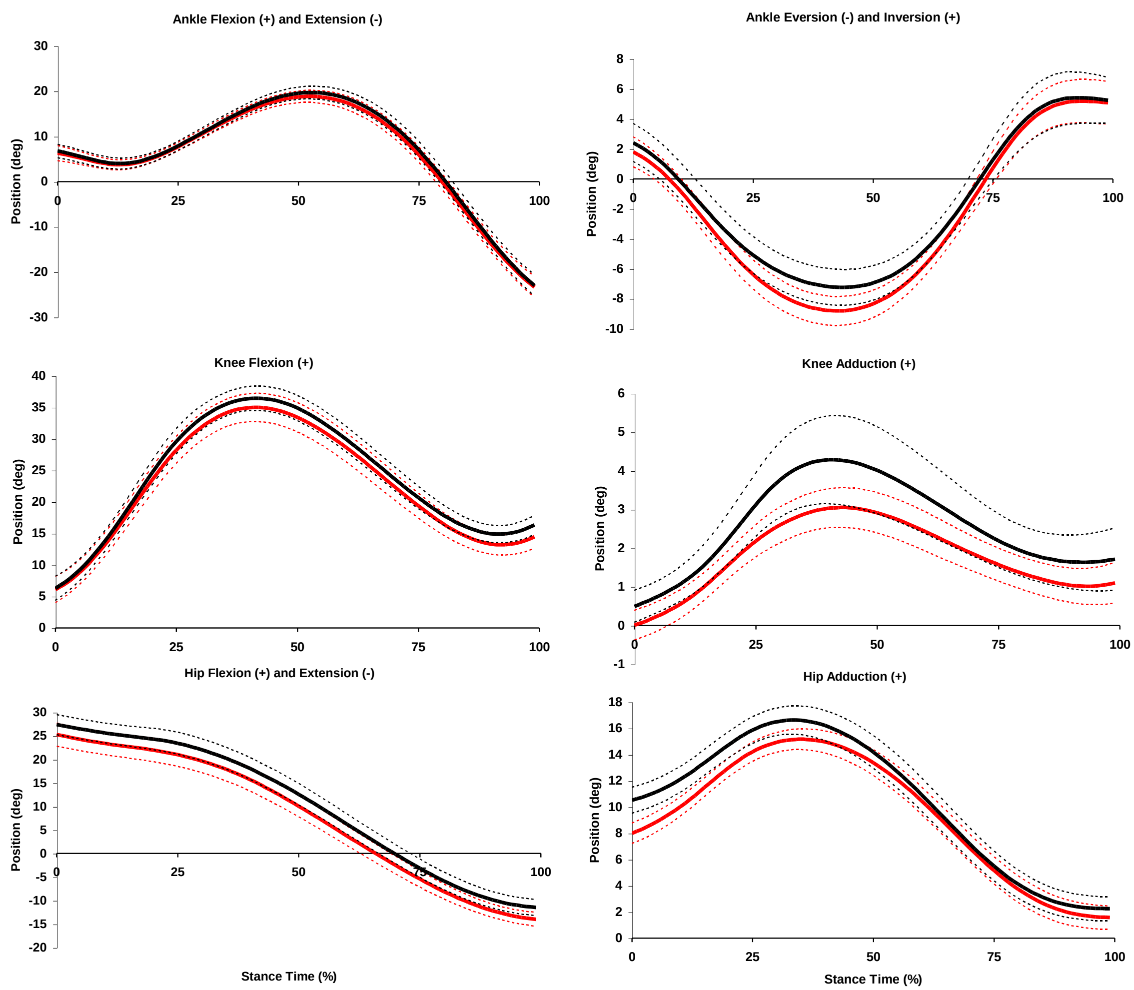
Ankle Flexion (+) and Extension (-)
Ankle Eversion (-) and Inversion (+)
Knee Flexion (+)
Knee Adduction (+)
Hip Flexion (+) and Extension (-)
Hip Adduction (+)
Position (deg)
Stance Time (%)
0
25
50
75
100

Figure 3.

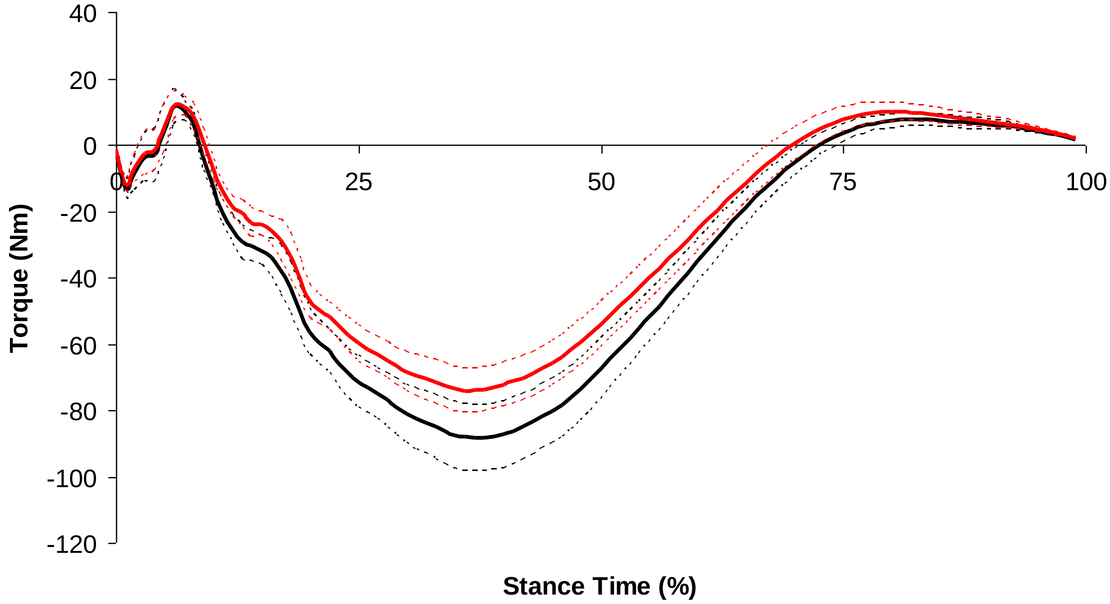

FIGURE LEGENDS

Figure 1. The Opedix knee support garment.

Figure 2. The mean (± standard error) sagittal and frontal plane kinematics for the hip, knee and ankle during running while wearing the control (black lines) and the Opedix (red lines) garments.

Figure 3. The mean (± standard error) external knee adduction moment during the stance phase of running while wearing the control (black lines) and the Opedix (red lines) garments.