Contralateral Shoe-Lift: Effect on Oxygen Cost of Walking With an Immobilized Knee

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Objective: Evaluate the effect of a contralateral shoe-lift on the oxygen cost of walking with an artificially immobilized knee.

Design: A prospective quantitative evaluation of oxygen cost of walking under varying conditions. Subjects walked (1) normally (N), (2) with one knee immobilized (I), (3) with one knee immobilized and with a one-half-inch shoe-lift applied to the contralateral shoe ($I_{1/2}$L), and (4) with one knee immobilized and with a one-inch shoe-lift ($I_1$L).

Setting: Exercise physiology laboratory.

Subjects: Ten able-bodied subjects without known cardiopulmonary or musculoskeletal problems.

Main Outcome Measure: Breath-by-breath oxygen consumption measurements in mL/kg/m.

Results: Oxygen cost on average was 20% more with the knee immobilized (I) compared to normal (N) (mean difference $= 0.0298 \pm 0.0245\text{mL/kg/m}$, $p = 0.002$). Oxygen cost was significantly less (11% versus 20% above that of normal walking) with the half-inch shoe-lift (mean difference between $I_{1/2}$ and $I = 0.0167 \pm 0.0138\text{mL/kg/m}$, $p = 0.002$). Similarly, oxygen cost was significantly less (12% versus 20% above that of normal walking) with the one-inch shoe-lift (mean difference between $I_1$ and $I = 0.0142 \pm 0.0116$, $p = 0.002$).

Conclusion: This study demonstrates that a subject with an immobilized knee requires less energy to walk with a contralateral shoe-lift and provides scientific evidence for prescribing a shoe-lift on the contralateral foot when the ipsilateral knee is immobilized in full extension. This practice is not universally accepted and to our knowledge has not been reported in the literature. The purpose of this study is to scientifically evaluate the effect, with respect to oxygen cost, of wearing a shoe-lift on the contralateral foot when the ipsilateral knee is immobilized in full extension. This experimental design should provide scientific support for prescribing a contralateral shoe-lift for patients who are unable to flex their ipsilateral knee.

METHODS

Ten able-bodied subjects, 5 men 5 women, participated in this study. Subjects on any medication or with any known cardiopulmonary, musculoskeletal, neurological, or gait disorder were excluded. The methods were approved by the Institutional Review Board and an informed consent was obtained from each volunteer. The average age of the subjects was 30.54 ± 12.98yr, the average height was 165 ± 9.26cm and the average weight was 60.62 ± 10.45kg. The study consisted of four stages, the order of which was randomized for each subject. In each stage the subjects walked wearing their regular shoes with no shoe-lift or knee immobilizer applied. In another stage, the subjects had an external knee immobilizer applied unilaterally to maintain the right knee in full extension throughout the gait cycle. In another stage, subjects wore a one-half-inch shoe-lift made of cork, which extended the length of the shoe and was strapped to the sole of the left shoe with duct tape. In another stage, a one-inch shoe-lift was used. For each stage, subjects were asked to walk at their comfortable walking speed across a smooth level surface. The time that the subject needed to walk 20 feet was measured. This was repeated five times for each stage. From these measurements, an average comfortable walking speed (CWS) for each stage was calculated.

Subjects were asked to walk on a motorized treadmill for each of the 4 stages. While walking on the treadmill, the subjects breathed through a non-rebreathing valve connected by flexible tubing to a metabolic cart, which analyzed the amount of oxygen utilized on a breath-by-breath basis. A tight lip seal around the mouthpiece was ensured to prevent air leak around the mouth and a nose clip was applied to prevent air leak through...
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Fig 1. Overall average walking efficiency (VO2: mL/kg/m) at CWS for the ten subjects during the different stages of the study: N, normal walking with no knee immobilizer and no shoe-lift; l, knee immobilizer but no shoe-lift; l$L, knee immobilizer and half-inch shoe-lift; ll$L, knee immobilizer and one-inch shoe-lift.

the nose. The mouthpiece and the tubing were supported by a head set. Electrocardiographic leads were applied for continuous heart rate (HR) monitoring. At the start of the trial, the subject stood on the treadmill while resting oxygen consumption was measured over 3 minutes. Because the energy cost of walking is speed-dependent,5,6 and because walking is most efficient when the speed is close to the CWS of a given individual,7,8 the treadmill speed was set at the corresponding CWS for each of the four stages. Oxygen cost, expressed in mL/kg/m, was measured for each stage over 3 minutes after the HR reached a steady state (usually 3 minutes after beginning to walk). The oxygen cost measurement was normalized by the subject's body weight and the distance traversed. Between each stage subjects were allowed to rest until the resting HR (pre-start HR) was attained. All subjects finished the study with good tolerance and no complications. The average oxygen cost, CWS, and HR values for each stage of the study were compared. First, an overall evaluation was done using an analysis of variance (ANOVA) repeated measures test. Individual comparisons were also made using a two-tailed paired t test. Statistical significance was defined as a p value less than .05. Unconditional logistic regression was performed to assess the combined predictive value of height, weight, and age in estimating whether or not a particular subject would have a better walking efficiency with the one-inch versus the one-half-inch shoe-lift. All statistical tests were performed using the statistical package True Epistat.9

RESULTS

The ANOVA repeated measures test for oxygen cost among the four stages was statistically significant (p < .001). When the subjects had their knees immobilized unilaterally in full extension, oxygen cost for walking was significantly greater by an average of 20% compared to normal walking (mean difference = .0298 ± .0245mL/kg/m, p = .002). Oxygen cost was significantly less (11% versus 20% above that of normal walking, mean difference = .0167 ± .0138mL/kg/m, p = .002) for the stage with the half-inch shoe-lift. Similarly, oxygen cost was significantly less (12% versus 20% above that of normal walking, mean difference = .0142 ± .0116, p = .002) for the stage with the one-inch shoe-lift (fig 1). There was no statistically significant difference in oxygen cost between the stages with the one-half-inch and one-inch shoe lift (p = .97). Furthermore, a one-half-inch or one-inch shoe-lift to the contralateral foot of the immobilized extended knee resulted in a decrease in oxygen cost during walking at CWS in each of the ten subjects (fig 2). In six subjects, walking with a half-inch shoe-lift at CWS was more efficient than with the one-inch shoe-lift. In the other four subjects, walking was more efficient with the one-inch shoe-lift. Unconditional logistic regression demonstrated that height, weight, and age were not statistically significant factors in determining whether or not a particular subject would have a greater improvement in efficiency with the one-half versus one-inch shoe-lift.

There was no statistically significant difference in HR among the four stages (ANOVA repeated measures p = .69) (fig 3). There was a significant reduction in the CWS with the knee immobilizer (l) compared to normal walking (N) (mean difference = .56 ± .16m/sec). When compared to the stage with the knee immobilized, the addition of a shoe-lift resulted in a slight increase in CWS in 5 subjects, a reduction in CWS in 1 subject, and no change in 4 subjects. These subtle differences, which were not statistically significant (ANOVA repeated measures p
The finding in the present study that the oxygen cost of walking increased by 20% with the knee immobilized compared to normal is in accordance with the literature.

There are likely multiple biomechanical mechanisms responsible for the improved walking efficiency with the shoe-lift. The shoe-lift on the limb contralateral to the immobilized knee probably reduces the need on this side for vauling and knee hyperextension during the stance period. Similarly, the shoe-lift likely reduces the need for hip hiking and circumduction during the swing period on the immobilized knee side. All of these four mechanisms would tend to reduce the vertical displacement of the center of mass during walking and thereby improve walking efficiency.

The energy cost of walking can be the limiting factor in an individual's ability to ambulate. This is especially true for people with disabilities. Probably any reduction in the energy cost of walking will enhance their ability to walk and advance their functional status. It is not uncommon for a hemiplegic stroke patient or a person with an above-knee amputation to have cardiovascular or pulmonary impairments that further compromise their ambulating capability. Improvement in walking energy cost could be the deciding factor enabling the patient to ambulate. The findings of this study may be translated to other patients who are unable to flex one of their knees. Those individuals who benefit from a contralateral shoe-lift include patients with knee fusion, knee immobilization either temporary or permanent secondary to casting or orthotics, above-knee prosthesis with no knee mechanism, and spastic paretic stiff-legged gait with upper motor neuron disease. In an above-knee amputee with a locked knee prosthesis, a shorter prosthetic limb would be more appropriate than a shoe-lift on the contralateral side.

In conclusion, this article provides scientific evidence favoring the use of a shoe-lift in patients who unilaterally cannot flex their knees. Since the one-half-inch and the one-inch shoe-lift had similar results on walking efficiency, and since subjects were more comfortable with the one half inch shoe lift, prescribing a one-half-inch shoe-lift is reasonable. Further study of the kinematics and kinetic effect of a shoe-lift is in progress.

References

Suppliers
a. DePuy, P.O. Box 988, Warsaw, IN 46581-0988.
b. Sensor Medics, 22705 Sadi Rasch Parkeway, Yorba Linda, CA 92687.
c. Epistat Services, 2011 Cap Rock Circle, Richardson TX 75080.