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The Effect of Lower Leg Casting on Energy Cost During Independent Ambulation: Considerations for Clinical Practice

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ABSTRACT
Purpose: The purpose of this study was to investigate the effects of dominant leg, lower leg casting on energy cost during independent ambulation. The Physiological Cost Index, predicted VO_{2max}, and gait speed values of a Quarter-Mile Walk Test, with and without lower leg casting, were utilized to determine energy cost. **Methods:** Thirty-five subjects who were 23 to 32 years old (mean age 25.37 ± 2.02) performed the Quarter-Mile Walk Test at their comfortable walking speed on two occasions, one with and one without lower leg casting. Resting heart rate, walking heart rate, and time to complete the test were recorded. Physiological Cost Index, predicted VO_{2max}, and gait speed formulas were used to calculate results. **Results:** Physiological Cost Index increased when walking with the lower leg cast, but was not statistically significant (p=.3939). A statistically significant decrease was seen with predicted VO_{2max} (p<.0001) and gait speed (p<.0001) when walking with a lower leg cast. **Conclusions:** PredictedVO_{2max} and gait speed decreased when walking with a lower leg cast on the dominant leg. This finding indicates that as subjects altered their self-selected speed, predicted VO_{2max} decreased with gait speed.

INTRODUCTION
Bailey and Ratcliffe state that “assessment of energy expenditure during walking is an important parameter which can be used to determine clinical and functional improvements in patients with locomotor problems.”[1] “Locomotor problems” may arise when individuals are placed in lower leg casts for extended periods of time because of impairments such as full contact casting associated with wounds secondary to diabetes mellitus, orthopedic and neurological conditions, and serial casting. A question arises as to the change in walking performance associated with the addition of a lower leg cast on individuals. The increased work load placed on the body by the lower leg cast should be considered in these individuals. Findings of previous researchers have established the Physiological Cost Index (PCI) as a valid measure of energy cost.[1] PCI is a simple instrument to measure energy consumption and requires little equipment to administer and was established to determine energy cost.[1,2]

The measure is expressed as heart beats per meter:[3]

$$\text{PCI (beats/meter)} = \frac{\text{Walking heart rate (beats/min)} - \text{Resting heart rate (beats/min)}}{\text{Walking speed (meters/min)}}$$

The PCI has clinical utility because common equipment found in a clinical setting can be used to determine energy cost.[4-6] Although VO_2 is the standard measurement for energy cost, PCI is low-cost and more practical to use in a clinical setting because it does not require special training or administration in a laboratory setting using bulky equipment.[1,6-8] Cumbersome laboratory equipment necessary to measure oxygen consumption may adversely affect and alter the actual measurement.[1] The PCI criteria requires: 1) subject walks at his/her "comfortable walking speed" (CWS) or "preferred pace;" 2) steady state resting heart rate established following a five minute rest period; 3) walking heart rate obtained at steady state. [2,4,8] PCI demonstrates the linear relationship that exists between heart rate and VO_2.[5] This instrument has been used to analyze energy cost in healthy individuals as well as those with pathological conditions; however, PCI has not been utilized to demonstrate energy cost in healthy individuals with temporary impairments including lower leg casting.[1,2,4,5]

VO_{2max} is defined as the maximum amount of oxygen that can be transported and utilized by the body per minute.[9] For the purpose of this study, predicted VO_{2max} was used as an additional measurement of energy cost in healthy individuals with lower leg casting. A study by Greenhalgh et al showed cross validation of a ¼ mile walk test with the 1-mile walk test and suggested that "the ¼ mile test predicted VO_{2max} with about the same accuracy as the 1-mile walk."[9] That study used a similar approach to predict $VO_{2max}$for a Quarter-Mile Walk Test (QMW) except that the elapsed time was multiplied by four. The VO2 max was calculated by using the formula:

$$VO_{2max}\ \text{(ml/kg/min)} = 132.853 - 0.0769(\text{wt.}) - 0.3877(\text{age}) - 3.2649\ (\text{time} \times 4) - 0.1565(\text{HR}) + 6.315\ \text{for males only.}$$[9]

Gait speed is commonly used in the clinical setting as a functional outcome measure to determine both health and functional status in the older adult.[10] Gait speed has been shown to be a valid and reliable predictor of falls, hospitalizations, and mortality when administered to the elderly.[10,11] Gait speed is calculated by dividing the distance walked by the time taken to finish the walk and is quantified in meters per second (m/s).[11,12] Normal walking speed for adults is 1.2-1.3m/s.[13-15] The test is easily administered because it requires little space and equipment.[11]

Previous researchers have shown the PCI and predicted VO_{2max} to be valid measures of energy cost.[1,5,8,9] Bailey and Ratcliffe determined PCI to be valid and reliable based on multiple test-retest situations in both steady-state and non-steady-state. These situations resulted in minimal differences in values for "normal subjects."[1]

Peoples et al used the PCI to compare treadmill and floor walking with elderly subjects.[2] Danielsson et al used the PCI to measure energy cost in walking for subjects after a stroke.[7] Hagberg et al used the PCI to compare walking performance of individuals with transfemoral prostheses and healthy controls.[4] This present study will investigate walking performance of individuals without impairment with and without a lower leg cast. Lower leg casting is commonly applied in the form of serial casting in the pediatric population and also used as an intervention for various medical issues such as fracture and surgical corrections of orthopedic problems. No studies have been found which determine the effect of walking with lower leg casting on PCI, predicted VO_{2max}, and gait speed.

This study was designed to investigate the effects of lower leg casting on dominant leg on energy cost using the PCI, predicted VO_{2max} and gait speed values following a QMW. The authors hypothesize the PCI would increase following completion of the QMW with lower leg casting. It was also hypothesized that there will be a negative correlation between the Physiological Cost Index and the predicted VO_{2max}.

METHODS

The study protocol was reviewed and approved by the University Institutional Review Board (IRB). The study adhered to the procedures approved by the University IRB and the Health Insurance Portability and Accountability Act (HIPAA) guidelines. Informed consent forms were read and signed by all subjects.

Subjects

Thirty-five healthy male and female subjects mean age 25.37 ± 2.02 years, mean height 67.31 ± 4.87 in., and mean weight 166.7 ± 41.26 lbs. participated in this study. Participants were graduate students free from integumentary, cardiopulmonary, neuromuscular, or musculoskeletal complications as determined from information provided in the Physical Activity Readiness

Questionnaire (Par-Q). Participants were randomized to account for a learning effect. Group 1 consisted of 18 subjects mean age 25.06 years (age range 23 to 32). Group 2 consisted of 17 subjects mean age 25.71 years (age range 24 to 32).

Protocol
Participants were tested independently and completed a practice QMW prior to data collection. Group 1 completed the QMW without lower leg casting five to nine days prior to performing the QMW with lower leg casting. Group 2 completed the QMW with lower leg casting five to nine days prior to completing the QMW without lower leg casting.

A quarter-mile distance was measured on three indoor continuous rectangular corridors using a standard measuring wheel to eliminate the influence of weather conditions. Three corridors were chosen to make the data collection more efficient. Participants were escorted by their assigned researcher to one of three indoor corridors to complete the QMW. Participants were escorted to insure that no one took the stairs or ran to the testing area. Data were collected by 3 individuals. These individuals were trained to administer the test and performed pilot testing prior to collecting data for this project. Instructions given by each researcher was standardized so that each participant received the same instructions.

Participants were required to wear comfortable clothing while completing the QMW. Each participant's height and weight were measured on a stadiometer and recorded by the same researcher. The Lateral Preference Inventory was administered to participants to determine foot dominance.[16] Participants were casted with the dominant foot at 90° using 3M Soft Cast material and a Hely & Weber cast shoe was worn while performing the QMW. Cast shoe size was determined using a size chart provided by a licensed orthotist.

Participants were given a five minute rest period prior to starting the test in order to establish a resting heart rate. A MEDIAID (17517 Fabrica Way Suite H, Cerritos, CA 90703) pulse oximeter was placed on the participants' index finger and resting heart rate was recorded. Participants were instructed to walk at their CWS and refrain from talking for the duration of the QMW. Participants concluded the QMW at the designated stopping point, and time to complete the test was recorded using a standard stopwatch. The pulse oximeter was placed on the participant's index finger and walking heart rate was recorded, which concluded the study.

Equations used for calculations:

$$\textbf{PCI}\ (\text{beats/meter}) = \frac{\text{Walking heart rate} - \text{Resting heart rate(beats/min)}}{\text{Walking speed (meters/min)}}$$

$$\textbf{VO}_{\textbf{2max}}\ (\text{ml/kg/min}) = 132.853 - 0.0769(\text{wt}) - 0.3877(\text{age}) - 3.2649\ (\text{time} \times 4) - 0.1565(\text{WHR})\ ^* + 6.315 \text{ for males only}$$

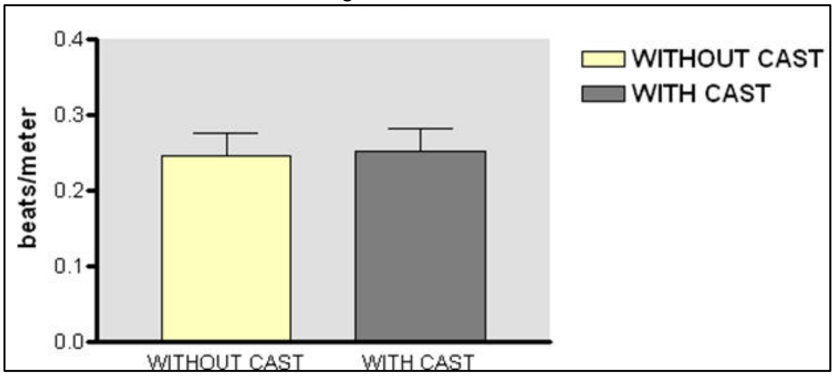
$$\textbf{Gait Speed}\ (\text{m/s}) = \frac{402.3 \text{ meters}}{\text{time (seconds)}}$$

Statistical Analysis
PCI, predicted VO_{2max}, and gait speed values were calculated for each participant using the formulas previously stated. Means and standard deviations of age, height, weight, PCI, predicted VO_{2max}, and gait speed were analyzed for each group. PCI, predicted VO_{2max}, and gait speed values between each group were compared with paired t-tests. The alpha level was set at 0.05.

RESULTS

Physiological Cost Index
There was a slight increase in PCI for each group when performing the QMW with the cast applied; however, this change was not statistically significant ($t=0.2714$; $p=0.3939$, $df=34$). Mean PCI without the cast applied was 0.2455 ± 0.1856 beats/meter. Mean PCI with the cast applied was 0.2526 ± 0.1716 beats/meter.

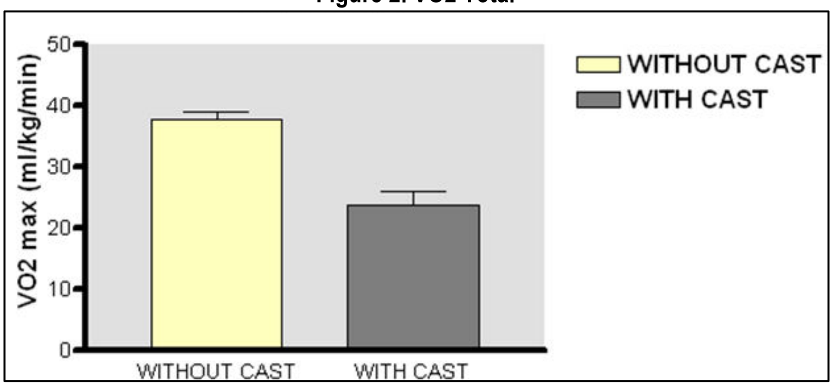
Figure 1. PCI Total



Predicted VO_{2max}

A statistically significant difference was found when comparing the QMW with and without lower limb casting in VO_{2max} for each group. Statistical analysis showed there was a decrease in VO_{2max} (t=6.927; P<0.0001, df=34). Mean VO_{2max}without the cast applied was 37.82 ± 7.057 ml/kg/min. Mean $VO_{2max}$with the cast applied was 23.66 ± 13.56 ml/kg/min.

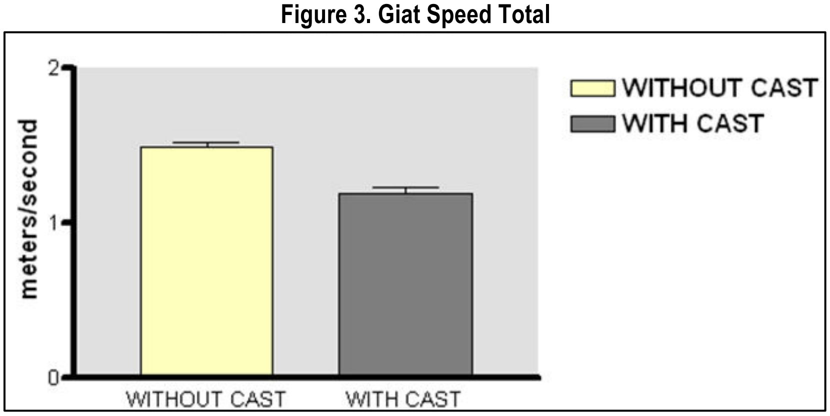
Figure 2. VO2 Total



Gait Speed

A statistically significant difference was found when comparing QMW with casting and without casting in gait speed for each group. Statistical analysis showed there was a decrease in gait speed (t=9.186; P<0.0001, df=34) when walking with the lower limb cast. Mean gait speed without the cast applied was 1.488 ± 0.1757 m/sec. Mean gait speed with the cast applied was 1.194 ± 0.1894 m/sec.

Figure 3. Giat Speed Total



DISCUSSION

This study used the PCI, predicted VO_{2max}, and gait speed to investigate the energy cost in healthy individuals ambulating with lower leg casting. Although there was not a statistically significant difference in PCI values, there was a slight increase in PCI with a lower leg cast. The statistically significant decrease in both predicted VO_{2max} and gait speed while walking with a lower leg cast indicates an accommodation of decrease output while walking with a lower leg cast. A decrease in predicted VO_{2max} may indicate the subject was unable to utilize the maximal amount of oxygen as a result of the increased work load placed on the body by the lower leg cast. This is an important consideration when individuals may have to continue with previous ADLs while wearing a temporary lower extremity cast. The decreases also may be the result of the subject accommodating to the lower limb cast by decreasing gait speed which decreased energy requirements. The statistically significant decrease in both predicted VO_{2max} and gait with casting indicated a decrease in self-selected walking speed referred to by Plasschaert et al.[17] Bailey and Ratcliffe calculated PCI on a test-retest basis. They used steady-state, non-steady-state, and 10-second post-exercise HR values and found the PCI to be a reliable measure; however, they stressed that "whichever method is used, the protocol should be strictly adhered to."[1]

Lower limb casting may be applied to various populations including those with plantar ulcers, diabetes mellitus, and other chronic sensory neuropathies.[18] Serial casting is also used to maintain proper ankle position to promote efficient function of gastrocnemius muscles in children with cerebral palsy.[19] Awareness of increased energy cost placed on the body by lower leg casts should be considered by healthcare providers when treating these individuals. Individuals with lower leg casts may utilize assistive devices; but this present study did not include the addition of an assistive device.

Because individuals with neurological impairments and numerous other dysfunctions are often placed in temporary lower leg casts, including serial casts, for extended periods of time, therapists should include activities to improve efficiency for this new functional activity of ambulation with lower leg casting. This study utilized healthy subjects, which could serve as a baseline for future studies that examine the energy cost and gait speed of individuals with impairments walking with a lower leg cast, such as full contact casting in individuals with wounds secondary to diabetes, orthopedic impairments, neurological conditions, and serial casting.

Limitations

The selection of individuals without physical limitations can be viewed as a limitation. This group was selected to provide a baseline as limitations add additional variables even within the same medical diagnosis group. Another limitation of this study includes walking on an indoor corridor with sharp turns and the application of lower leg casts. Previous research reported sharp turns cause deceleration in CWS, which alters PCI values.[7] CWS can be more accurately measured if the walkway used during testing avoids stops and turns.[1] In the present study, the same route was utilized for CWS with and without casting, so this should not present an issue with statistical analysis. There is an inherent inconsistency in the application of lower leg casts. An attempt to control this was made by utilizing a standard method of casting that included goniometric measurements taken and the dominant foot of each participant casted at 90°. No correction was made to the non-casted limb to compensate for the increased height due to cast and cast shoe on the casted limb. Although this is an important consideration, it is not something that is always compensated for in the "real world." The age of subjects may also be seen as a limitation, and future research should include geriatric and pediatric populations.

VO_{2max} testing is traditionally performed with treadmill walking; however, previous research demonstrated that floor walking at CWS offers a more functional medium than the treadmill for assessing PCI because treadmill walking required increased energy cost.[7] Another factor considered for utilizing indoor corridors was a concern of the safety of walking on a treadmill with a lower limb cast.

This study provides a baseline for individuals without functional limitations. Future studies should include children without functional limitations, adults and children with functional limitations, and use of assistive devices.

CONCLUSION

Previous researchers have demonstrated how spasticity present in children with cerebral palsy impaired gait patterns and considerably increased energy expenditure.[20] Although this present study was associated with healthy, adult individuals, it is applicable to individuals who become "temporarily disabled" and can be used as a baseline for individuals with disabilities.

In this present study, casting of the lower extremity in individuals without other impairment resulted in a significant decrease in gait speed and predicted VO_{2max} as evidenced by self-selected walking speed. The clinical implications include consideration of including endurance activities in the treatment plan of individuals who may become temporarily "disabled" and decrease self-selected pace for walking or ADL's. This decrease in self-selected pace will lead to loss of endurance if appropriate interventions are not included in the treatment plan.

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KEY TERMS
Physiological Cost Index, Gait Speed, Predicted VO_{2max}, Quarter-Mile Walk, Comfortable Walking Speed