METABOLIC EVALUATION OF THE CRITERIA USED TO FIT ELBOW CRUTCHES BY MEASUREMENT OF OXYGEN CONSUMPTION

Toby R. Smith, BSc(Hons), Stephanie Enright, MSc


Objective: To investigate if elbow crutches fitted using conventional guidelines are the most metabolically efficient.

Design: Repeated measure connivance sample using crutch length as the independent variable.

Setting: A university exercise physiology laboratory.

Other Participant: Connivance sample of 10 students free from cardiovascular disease, with previous experience in crutch ambulation, and between the heights of 160 and 175cm. Four potential subjects refused to participate in the study.

Interventions: Crutch length was adjusted using conventional guidelines, and to lengths 2.5cm above and below this setting. Oxygen consumption was measured using indirect open-circuit spirometry during the final 3 minutes of ambulation using self-selected walking speeds.

Main Outcome Measure: Crutches adjusted to the conventional setting are not the most efficient in terms of metabolic energy expenditure.

Results: A significant reduction in oxygen rate (p = .012), oxygen cost (p = .010), and respiratory exchange ratio (p = .009) were observed when comparing crutches adjusted to 2.5cm of the standard height with conventional crutch height. Crutches adjusted 2.5cm above the standard height also required less energy, but these values failed to reach any statistical significance (p > .05).

Conclusion: The importance of fitting crutches to the correct length using conventional guidelines has not been substantiated in this study. Clinically, there should be a move away from adherence to crutch-fitting criteria and more incorporation of patient feedback to fit crutches to the optimal height. Future research should evaluate the reliability of practical clinical measures such as heart rate and perceived exertion to fit crutches to the optimal height.

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ELBOW CRUTCHES are frequently distributed to patients with ambulatory difficulties, and the relationship between energy expenditure and crutch-assisted gait has been extensively studied. The importance of fitting crutches to the correct length has been documented by many authors. Guidelines for the correct fitting of crutches have been published by numerous authors, but surprisingly, there has only been one study that has attempted to quantify the measurement criteria used to fit elbow crutches. The scientific basis for the fitting of elbow crutches has received little attention, and previous fitting guidelines have been based on subjective measures of gait quality rather than quantifiable measures of gait and metabolic efficiency.

No study has attempted to investigate the relationship between crutch length and energy expenditure. The high cardiovascular stress of crutch ambulation has been well documented. Metabolic investigation into crutch-fitting criteria could find an optimum energy-efficient crutch height and reduce the stress of crutch ambulation, thereby enabling ambulation to be sustained for a longer duration and greater attainment of activities of daily living. This study was subsequently undertaken to evaluate oxygen consumption (VO2), heart rate, and respiratory exchange ratio responses to ambulation using conventional fitted elbow crutches and adjusted crutch lengths to determine if there is a single optimum crutch height, in terms of metabolic energy expenditure.

METHODS

Ten healthy subjects, 7 women and 3 men with a mean age of 22.2 years ± 8.8 (SD, 3.3), weight 67.2kg ± 27.8 (SD, 10.3), height 166.9cm ± 8.1 (SD, 3.9), were selected for the experiment. Their anthropometric data are shown in table 1. Subjects were free from any cardiovascular disease and have had previous experience ambulating with elbow crutches.

Subjects between 160 and 175cm in height were selected to reduce the possible effects of this variable on the data. Subjects gave their verbal consent to participate in the experiment and had the right to withdraw from the experiment at any point if they so wished. All data was confidential.

Measurements of height and weight were recorded for each subject. The dominant lower limb was determined by observing which leg the uninstructed subject used to step onto a stool. The standard crutch height was measured for each subject by aligning the hand grips of the crutch to the greater trochanter and the base of the crutch with the sole of the foot.

Subjects were then instructed to use a 3-point non-weight-bearing (NWB) swing-through gait, the NWB leg was standardized by using the nondominant lower limb. Standard adjustable elbow crutches were used. The crutches were slightly modified by placing some tape around the hand grips to prevent slipping. Subjects then practiced this mode of ambulating for 5 minutes. Before testing, the velocity (comfortable walking speed [CWS]) for each subject had to be established. This was determined with the subject ambulating on motorized treadmill, at a 0° gradient, using conventional crutch height. The velocity of the treadmill was adjusted by increasing and decreasing the speed until the subjects expressed that they were comfortable ambulating at that velocity. The CWS for each subject was recorded. Each subject would perform three tests in random order using conventional height-adjusted crutches, crutches adjusted 2.5cm
above the conventional height and crutches adjusted 2.5cm below the conventional height. The heights of ±2.5cm corresponded to altering the crutches up or down one adjustment hole, respectively. There was a 24-hour interval between each test, and subjects used the same CWS for all three tests.

A Polar Sportstester ECG-calibrated heart rate monitor was placed around the subject’s chest, with the receiver part of the monitor attached to the subject’s wrist and set to record heart rate values at 5-second intervals. Subjects were dressed in shorts, T shirt, and trainers. A disinfected mouthpiece and valve box was fitted and attached by means of a flexible tube to a Douglas bag, and a clean nose clip was also fitted. The heart rate data were downloaded onto an IBM computer using software by Polar. The oxygen and carbon dioxide content of the Douglas bag were measured by emptying the bag through a dry gas meter. Barometric pressure was measured using a barometer.

The oxygen analyzer was calibrated to 0°C and 760mmHg, respectively, and were dry. A parametric paired student t test was carried out using a computer-based statistical package to determine the significance between the mean energy expenditure for conventional crutch height and the mean energy expenditure for the altered crutch heights.

### RESULTS

The mean CWS was 28.38m/min ± 13.68 (SD 5.5). Table 2 shows the mean oxygen rate between different crutch heights;

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age</th>
<th>Height (m)</th>
<th>Dominant Leg</th>
<th>Weight (kg)</th>
<th>CWS (m/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>21</td>
<td>1.66</td>
<td>R</td>
<td>56.4</td>
<td>30.0</td>
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<td>2</td>
<td>M</td>
<td>31</td>
<td>1.75</td>
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<td>F</td>
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<td>1.69</td>
<td>R</td>
<td>65.5</td>
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The mean oxygen rate for the conventional crutch height required an 12.9% increase in oxygen rate (mL·kg⁻¹·min⁻¹) compared with crutches adjusted +2.5cm above the conventional height. Physiologically, this represented an additional 2mL·kg⁻¹·min⁻¹; however, this figure was of no statistical significance (p > .05). Figure 1 shows that crutches adjusted to −2.5cm below the conventional setting were 19.2% more efficient in terms of their oxygen consumption compared with the conventional height-adjusted crutches. This represented a significant decrease of 2.8mL·kg⁻¹·min⁻¹ (p < .05).

The mean oxygen cost (mL·kg⁻¹·m⁻¹) for the conventional height-adjusted crutches (table 2) was 11.7% greater compared with crutches adjusted +2.5cm of the conventional setting. This nonsignificant figure relates to an additional .067mL·kg⁻¹·m⁻¹ (p > .05). A significant decrease of 17.9% was observed when comparing crutches of −2.5cm with the conventional height. This corresponds to a decrease of .097mL·kg⁻¹·m⁻¹ (p < .05). The relationship between the oxygen cost and crutch height is displayed in figure 2.

The mean RER of 97 for conventional crutch height was 7% greater (.06), when compared with crutches adjusted to +2.5cm. This figure was not significant at the 95% confidence level (p > .05). A significant decrease in the RER of 9.4% (.07) occurred when comparing crutches of −2.5cm with the conventional height, (p < .05) (fig 3).

The mean heart rate for standard height crutches of 124beats·min⁻¹ (fig 4) was 6.2% (8beats·min⁻¹) and 8.8% (10beats·min⁻¹) greater when compared with crutch heights +2.5cm and −2.5cm, respectively. These values were not of any statistical significance (p > .05).

### DISCUSSION

#### Conventional Height Crutches

The study identifies that the average CWS of 28.38m/min is notably slower than in previous studies and falls well below

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Table 1: Anthropometric Data

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Table 2: Mean Values of Energy Expenditure for Different Crutch Heights

<table>
<thead>
<tr>
<th>Height</th>
<th>Oxygen Rate (mL·kg⁻¹·min⁻¹)</th>
<th>Oxygen Cost (mL·kg⁻¹·m⁻¹)</th>
<th>RER</th>
<th>Heart Rate (beats·min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>17.89</td>
<td>.638</td>
<td>.97</td>
<td>124</td>
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<tr>
<td>+2.5 cm</td>
<td>15.84</td>
<td>.571</td>
<td>.91</td>
<td>117</td>
</tr>
<tr>
<td>−2.5 cm</td>
<td>15.0</td>
<td>.541</td>
<td>.90</td>
<td>114</td>
</tr>
</tbody>
</table>

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![Fig 1. The relationship between crutch height and oxygen consumption.](image)

![Fig 2. The relationship between oxygen cost and crutch height.](image)
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what has been hypothesized to be the most efficient crutch walking speed. Slow CWS has been attributed to reduced cadence, shortened step length, and difficulties maintaining balance and rhythm. Balance has been identified as the key element that has to be attained before routine ambulation is possible. Fisher and Patterson identified a decrease in heart rate and oxygen rate with practice. McBeath and colleagues suggested the more skilled crutch user may select faster walking velocities. The slow walking speeds in this study appear to be due to insufficient familiarization with treadmill ambulation. A longer practice should have been used to enable greater familiarization with treadmill ambulation and a more accurate measurement of CWS.

Olsson and Smidt emphasised that when studying gait, there are significant differences between treadmill and level ground ambulation. Level terrain ambulation gives a more accurate reflection of the clinical setting and reduces the difficulty that is associated with treadmill ambulation. The use of level terrain ambulation would have been more representative of the clinical setting.

Clinically, it would be logical to propose that as a patient gains familiarity with the technique of crutch ambulation there may be a reduction in the forces directed in a medial direction to maintain balance. Thus, more force would be applied in an anterior/posterior direction, which would result in a greater horizontal displacement in the center of gravity per step and, subsequently, a reduction in oxygen cost and an increase in velocity.

The duration of ambulation is determined by the oxygen rate (mL·kg⁻¹·min⁻¹). The data shown in table 1 for conventional crutch height correspond to a level in excess of 70% of maximum aerobic capacity (Vo₂ max) in the age range of 65 to 75 years. Clearly, in this age group ambulation at this intensity level could not be sustained for a prolonged duration. Consequently, there would be a reduction in gait velocity in an attempt to reduce the oxygen rate and thus increase the duration of ambulation.

The measure of gait efficiency is reflected by the oxygen cost (mL·kg⁻¹·m⁻¹). Figure 2 shows three-point NWB crutch ambulation to be an extremely costly and inefficient mode of ambulation. It is important to recognize that the subjects were able to maintain this mode of ambulation for the full duration of the testing period because of the relatively low oxygen rate. This illustrates the importance of understanding the difference in the parameters of power (oxygen rate) and work (oxygen cost). The use of a fixed velocity protocol is open to criticism because it does not enable subjects to select a CWS for each crutch length, therefore not enabling a true measurement of oxygen cost.

The RER values in figure 3 suggest a moderate contribution from the anaerobic energy systems to meet the overall energy demand, and also suggest that the aerobic energy system in its entirety was insufficient to meet the energy demand for this mode of ambulation. The plateau in heart rate after approximately 2 minutes of ambulation indicates that steady state was attained (fig 4).

The heart rate data that appear in figure 5 exceed the target heart rate for a sedentary 50-year-old commencing an exercise program. It is ironic that all adults over the age of 35 years are recommend to undergo an medical examination before commencing an exercise program. Physicians and therapists, however, frequently distribute crutches to the elderly, which causes them to exceed typical safe heart rate values for their age. The decline in cardiovascular function resulting from aging, bed rest, and the presence of respiratory or cardiac pathology further increases the demands of crutch ambulation.

Clearly, there is a lack of knowledge about the physical demands of ambulatory aids and the inherent potentially grave consequences of exercising patients with impaired cardiovascular function at such high intensities. This study supports previous recommendations of caution when prescribing crutches to patients with cardiovascular disease. Furthermore, it may be necessary in certain circumstances to sacrifice functional independence for physical safety by selecting an alternate mode of ambulation and/or assistive device. More research is required.
to evaluate practical measures of cardiovascular conditioning in patients for whom ambulatory aids will be prescribed.

**Adjusted Crutch Heights**

Kinetically, the human body has developed to minimize the vertical displacement of the center of gravity (COG) in order for ambulation to take the pathway requiring the least energy expenditure. Compared with unassisted ambulation, crutch walking has a greater vertical and horizontal displacement of the body, with the greatest vertical displacement occurring at the shoulder. Crutch ambulation requires a large proportion of force to be directed in the medial to lateral direction to maintain stability.  

Crutches adjusted to -2.5 cm required significantly less energy expenditure when compared with conventional height-adjusted crutches. The lower levels of energy expenditure represent a decrease in muscular effort required for ambulation. This may be due a reduction in vertical displacement of the COG, which would result in the COG taking a more energy efficient pathway. Adjusting the crutches below the conventional height may have contributed to an increase in stability by bringing the COG closer to the base of support. Subsequently, a greater proportion of the impulses may be directed in an anterior/posterior direction to propel the body forward and result in savings in energy expenditure.  

The combination of increased stability and a reduction in the vertical displacement of the COG may account for the reduced levels of energy expenditure that were observed when using crutches adjusted to the -2.5 cm setting. The data in table 2 shows crutches adjusted to -2.5 cm had a lower intensity, in both measurement of oxygen rate and heart rate, indicating ambulation could be sustained for a longer duration compared with the other crutch heights. The lower oxygen cost identifies that the shorter crutch length is a more efficient mode of ambulation, with the other crutch heights. The lower oxygen cost identifies that the shorter crutch length is a more efficient mode of ambulation; subsequently, savings in energy expenditure may occur. Physicians and therapists must give greater consideration to the patient’s level of cardiovascular fitness and the physical demands of the ambulatory aid prescribed. More research is required on the importance of fitting elbow crutches to the correct length.

**CONCLUSION**

The importance of fitting crutches to the correct length using conventional guidelines has not been substantiated by this study. Shorter crutch lengths may be of benefit to patients with difficulties in maintaining balance or those who are unfamiliar in the technique of crutch ambulation; subsequently, savings in energy expenditure may occur. Physicians and therapists must give greater consideration to the patient’s level of cardiovascular fitness and the physical demands of the ambulatory aid prescribed. More research is required on the importance of fitting elbow crutches to the correct length.

**Acknowledgments:** The authors acknowledge the advice, support, and encouragement of staff and students at Brighton School of Physiotherapy, Eastbourne, England, and the facilities provided by Chelsea School of Physical Education, Sports Science, Dance and Leisure, Eastbourne.

**References**


 Suppliers
c. Servomex Laboratory Equipment, Crowborough, West Sussex, England