Detecting Postoperative Change in Children With Cerebral Palsy: Net Nondimensional Versus Body Mass Oxygen Normalization

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The aim of the study is to investigate whether the net nondimensional oxygen utilization scheme is able to detect postoperative improvement in the energy cost of walking in children with cerebral palsy and to compare it with a body mass normalization scheme. We evaluated 10 children with spastic cerebral palsy before and 9 months after equinus deformity surgery. Participants walked at a given speed of 2 km/hr and 3 km/hr on a treadmill. Oxygen utilization was measured, and mass relative VO2 and net nondimensional VO2 were calculated. Coefficient of variation was used for the description of variability among subjects. Postoperatively, gait kinematics normalized and the mass relative VO2 and net nondimensional VO2 showed significant improvement. Net nondimensional VO2 is able to detect postoperative improvement with smaller variability among subjects than body mass related normalization in children with cerebral palsy.

Keywords: exercise performance, orthopaedic surgery, gait analysis, kinematics

Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture causing activity limitation that are attributed to nonprogressive disturbances that occurred in the developing fetal or infant brain. Deformity, impaired function and limitation in mobility are key features of many of the children with cerebral palsy, which lead to referral to an orthopedic surgeon (Young & Wright, 1995). Measuring physical function is more difficult than measuring deformity, and measures of deformity are often used as surrogate measures for function (Graham et al., 2004).

Normal gait depends on an efficient use of energy, something that kinematic and kinetic gait data cannot directly measure. Conservation of energy is a typical aspect of walking. Children with cerebral palsy have been shown to expend greater energy during walking than their typically developing peers when walking at self-selected economical (Rose et al., 1990) as well as a given speed (Rose et al., 1993). Many factors influence energy expense while walking, including spasticity, bony deformity, strength and selective motor control. Thus, the energy cost of walking reflects the cumulative effect of many factors (Waters & Mulroy, 1999).

To quantify the energy cost of walking, oxygen consumption was used in previous studies (Dahlback & Norlin, 1985; Piccinini et al., 2007; Rose et al., 1989) because it gives an objective view of the overall efficacy of the patient’s gait. Schwartz pointed out the need to have a utilization measure independent of children’s age, weight and height to allow efficiency to be compared between subjects. Therefore Schwartz introduced a nondimensional normalization scheme for oxygen utilization data (Schwartz et al., 2006). Nondimensionalization is a form of normalization that renders parameters independent of original units of measurement. It decreases or even removes the impact of key anthropometric and physiological variables on the energy variables. This is important when comparing the energy cost of walking in children of different ages and morphology (Thomas et al., 2009). The nondimensional normalization scheme was found to be superior to body mass normalization, because it is only about one-fourth as sensitive to mass, height and age changes, and therefore provides a much more robust, reliable and properly interpreted measure of efficiency. (Schwartz et al., 2006). However, this scheme has not yet been used in assessing the effectiveness of soft-tissue surgery in children with cerebral palsy.

The aim of this study is to investigate whether the nondimensional oxygen utilization scheme is able to detect postoperative change in the energy cost of walking in children with cerebral palsy and to compare it to body mass normalization scheme.
## Methods

### Subjects

Ten children (4 girls, 6 boys) were included in this prospective study. The average age of our group of patients at the time of surgery was 8.4 ± 3.1 years (mean ± SD). Six children had a diplegic and 4 hemiplegic topographic distribution of spasticity. Partial body weight support reduces the oxygen cost of walking (Unnithan et al., 2006). Therefore, patients who were not able to walk on a treadmill without continuous holding of the bars were excluded. They were only allowed to touch the bars momentarily to maintain their balance. Two of the children used forearm crutches as their normal walking aid, but all participants were able to fulfill the above-mentioned criteria.

Children were community ambulators and were designated for gait corrective surgery for fixed equinus deformity. Two patients underwent additional adductor longus lengthening. All the other contraindications were assessed as dynamic (rectus femoris, hamstrings) and were addressed by conservative treatment. Patients suitable for corrective bony procedures and patients treated with botulinum toxin in the last six months were excluded. Parents’ approval of the study was given in written form and children agreed verbally. This study was approved by the local Ethical committee.

### Study design

Children were evaluated preoperatively and nine (9.33 ± 0.64) months postoperatively. Based on our previous study, the nine months period is a sufficient time for functional recovery after a surgery in children with cerebral palsy (Švehlík et al., 2008). Based on the findings that reliable physiologic and metabolic variables may be collected in subjects with mild cerebral palsy after one treadmill walking practice session (Maltais et al., 2003), exercise testing and gait analysis were carried out in two sessions at the same time of the day on separate days.

The first session (introductory visit) consisted of a physical examination, assessment of joint contractures, weight, height, lower limbs lengths and body adiposity assessment. Leg length was measured as the distance between the spina iliaca anterior superior and the tip of the medial malleolus using the medial condyle of the femur as a reference point if the knee extension was restricted.

Familiarization with walking on a treadmill (Marquette T2000) and respiratory gas analysis system (Oxycon beta, Jaeger, Hoechberg, Germany) was performed during 15 min of walking. Ability of participants to walk without holding on to bars at a given speed of 2 km·h⁻¹, 3 km·h⁻¹ and the velocity of comfortable walking speed were tested.

The second session took place a day after the introductory visit and selected parameters were recorded at rest and at a given speed of 2 km·h⁻¹ and 3 km·h⁻¹ at 0% gradient on treadmill. The monitored parameters were oxygen consumption (VO₂) and carbon dioxide production (VCO₂). The derived parameters were gross oxygen consumption relative to body mass (mass relative VO₂), nondimensional VO₂ (Schwartz et al.) normalized to leg length (Equation 1) and respiratory exchange ratio (RER).

The steady state was defined as a variation of both VO₂ and respiratory exchange ratio lower than 10% (McArdle et al., 2006) and was expressed as the average of the last 30 s of the four minutes stage. The steady state was reached in all patients.

\[
(\bar{O}_2^{\text{gross}} - \bar{O}_2^{\text{rest}}) \times \left( \frac{1}{mg} \sqrt{gL_{\text{leg}}} \right)
\]

where \(O_2^{\text{gross}} = \text{gross VO}_2\), \(O_2^{\text{rest}} = \text{resting VO}_2\), \(m\) = weight of the patient, \(g\) = gravitational constant, and \(L_{\text{leg}}\) = leg length.

Gait analysis was used to provide an objective measure of the postoperative improvement. Instrumented gait analysis was performed with eight-camera video based motion capture system (Proreflex 240Hz, Qualysis, Sweden), and provided three-dimensional kinematic and temporal-spatial parameters. Changes in the joint angles over the gait cycle were calculated using a seven-segment model using Euler angles (Visual3D, C-motion, USA).

Postoperatively, below-knee plaster casts were applied to all patients for six weeks. Physiotherapy followed the same protocol for all the patients and continued on an out-patient basis for the whole period of our study.

### Statistical Analysis

Statistical analysis was done using STATISTICA 6 (StatSoft, Tulsa, USA). Descriptive data are referred as mean ± SD. Student’s paired \(t\) test for dependent samples was used to compare pre- and postoperative values. \(P\)-value of less than 0.05 was considered statistically significant. Coefficient of variation (computed as standard deviation / mean) for both normalization methods was computed. Spearman rank correlation coefficient was used to assess the relation between the two methods.

### Results

The average height of our patients increased by mean 3.8 cm (range 1.7–5.3 cm), leg length increased by 2.6 cm (range 1.2–3.5 cm) and body weight increased by 1.9 kg (range 0.2–4.1 kg) during the postoperative period. The average comfortable walking speed (2.025 km·h⁻¹) did not change after the surgery. The level of Gross Motor Function Classification system was II-III (Palisano et al., 1997).

Gait analysis demonstrated normalization of the ankle motion. The ankle position at the initial contact changed from 9.6° of plantar flexion to 1.7° of dorsiflexion (\(p = .001\)) and the maximal dorsiflexion during the stance phase of the gait cycle increased from 1.7° to 12.2° (\(p = .022\)). Knee flexion angle at initial contact...
decreased from 33.2° to 21.1° ($p < .0001$). During single limb support, the knee flexion angle also decreased by 14.5° ($p < .0001$).

There was no difference between pre- and postoperative resting VO$_2$ and respiratory exchange ratio.

Oxygen utilization data are shown in Figure 1. There were significant decreases in both mass relative and nondimensional VO$_2$ parameters at 2 km·h$^{-1}$ as well as at 3 km·h$^{-1}$. Preoperative and postoperative coefficients of variation of the net nondimensional VO$_2$ were notably lower at both speeds when compared with mass relative VO$_2$ (Table 1). The Spearman rank correlation revealed a significant association between mass relative and net nondimensional VO$_2$ at both speeds preoperatively, as well as postoperatively (Table 2).

**Discussion**

Energy expenditure as measured by oxygen consumption can be considered as an objective tool for assessment of functional ability. It is an objective tool because it does not rely on parental or patient report and is also functional because its interpretation provides an indication of endurance, fatigue and ability to accomplish the routine daily task of locomotion. Fixed selected speeds of 2 km·h$^{-1}$

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**Table 1** Comparison of $P$-levels, coefficients of variation and confidence intervals of mass relative VO$_2$ (mL·min$^{-1}$·kg$^{-1}$) to nondimensional VO$_2$

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Parameter</th>
<th>$P$-level</th>
<th>Pre OP</th>
<th>CV Pre OP</th>
<th>Post OP</th>
<th>CV Post OP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 km·h$^{-1}$</td>
<td>Mass relative VO$_2$</td>
<td>0.0498</td>
<td>19.4 ± 4.3</td>
<td>1.4108</td>
<td>17.8 ± 2.7</td>
<td>0.9010</td>
</tr>
<tr>
<td></td>
<td>Net nondimensional VO$_2$</td>
<td>0.0068</td>
<td>0.57 ± 0.17</td>
<td>0.0531</td>
<td>0.50 ± 0.11</td>
<td>0.0375</td>
</tr>
<tr>
<td>3 km·h$^{-1}$</td>
<td>Mass relative VO$_2$</td>
<td>0.035</td>
<td>24.0 ± 3.3</td>
<td>0.9971</td>
<td>22.5 ± 2.5</td>
<td>0.8508</td>
</tr>
<tr>
<td></td>
<td>Net nondimensional VO$_2$</td>
<td>0.0333</td>
<td>0.76 ± 0.18</td>
<td>0.0556</td>
<td>0.70 ± 0.10</td>
<td>0.0351</td>
</tr>
</tbody>
</table>

*Note.* Pre OP = preoperatively, Post OP = postoperatively, CV = coefficient of variation.

**Table 2** Spearman rank correlation of the body mass relative and net nondimensional VO$_2$ normalization

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Mass Relative and Net Nondimensional VO$_2$ Correlation</th>
<th>Spearman $R$</th>
<th>$P$-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 km·h$^{-1}$</td>
<td>Pre OP</td>
<td>0.7697</td>
<td>0.0092</td>
</tr>
<tr>
<td>3 km·h$^{-1}$</td>
<td>Pre OP</td>
<td>0.8666</td>
<td>0.0024</td>
</tr>
</tbody>
</table>

*Note.* Pre OP = preoperatively, Post OP = postoperatively.

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**Figure 1** — Comparison of pre- and postoperative oxygen consumption results using two different normalization schemes. The asterisk (*) indicates statistical significance at $p < .05$. 

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and 3 km·h–1 should be comparable to speeds perceived in the patient’s everyday life (Unnithan et al., 1996). While resting oxygen consumption remained unchanged, gross mass relative oxygen consumption decreased and thus efficiency of walking increased. Postoperatively, the gait kinematics also considerably improved. Most of the oxygen, especially during locomotion or other exercise is used in energy metabolism. Lower oxygen consumption point out the lower energy demand and thus longer time until fatigue occurs. In contrast to healthy persons, the major reason for the increased energy cost of locomotion in children with cerebral palsy is ineffective gait, due to simultaneous activation of antagonist muscles (Unnithan et al., 1996; Unnithan et al., 1999). The preoperative values of VO2 in our group of children with cerebral palsy are considerably higher in comparison with values of the population of healthy children but similar to previously published data on children with cerebral palsy (Rose et al., 1993). Moreover, the comfortable walking speed is more than double in healthy subjects (Waters & Mulroy, 1999).

Because of the strong dependence of gross oxygen consumption on anthropometrical data there is a need for normalization. Gross oxygen consumption relative to body mass (mL·kg–1) is the most widely used parameter representing the intensity of physical effort during exercise. The mass relative normalization scheme provides widely accepted but not entirely effective normalization and its performance decreases with increasing height, mass and age (Schwartz et al., 2006). The net dimensional normalization scheme, using the nondimensional variables described by Hof (Hof, 1996), is essentially independent of all three above-mentioned factors. This scheme was shown to perform better than standard mass relative normalization in able-bodied children (Schwartz et al., 2006) and it was also used to evaluate gait efficiency in children with cerebral palsy (Brehm et al., 2008). To our knowledge, it has not been used to detect the improvement of gait efficiency after the soft-tissue surgery in children with cerebral palsy.

Our results demonstrate that the net nondimensional normalization enables a better pre- and postoperative comparison of energy consumption in children with cerebral palsy of different ages and anthropometrical parameters. This was reflected by the lower variability of the net nondimensional VO2 at both speeds when compared with mass relative VO2. Moreover, the Spearman rank correlation pre- and postoperatively indicates a close association between the two normalization methods.

In conclusion, the net nondimensional VO2 was able to detect the postoperative improvement of gait efficiency with smaller variability compared with standard mass relative normalization. Because of its independence on age, weight and height it might be recommended in studies concerning children with cerebral palsy.

References


