AEROBIC AND ANAEROBIC METABOLISM DURING LOCOMOTION WITH TWO DIFFERENT WHEELCHAIR TYPES

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The hand rim propulsion system generally employed by most wheelchairs (WHCH) presents a very low efficiency. This, coupled to the fact that propulsion requires the use of relatively small muscle mass, leads to the onset of fatigue even during low speed locomotion. To overcome these disadvantages different types of WHCHS have been designed in order to increase the efficiency of locomotion and thus to decrease the energy required to achieve a given speed.

Wheelchair confined subjects frequently report that locomotion with different types of daily use wheelchairs may induce quite different physiological responses. In particular, dyspnea and muscle fatigue can be easily achieved with a particular wheelchair type. On the contrary with other wheelchairs, even if apparently very similar in size, fatigue occurs at higher speeds.

In an attempt to realize the reasons for such a different response evoked by similar wheelchairs, a coupled bioenergetic–biomechanical analysis was performed. In the present paper the aerobic and anaerobic metabolism and the physiological responses to locomotion with two widely used wheelchairs was assessed. A large difference in the energy cost of locomotion and lactate production was observed between the two WHCH types investigated.

Material and methods

Subjects: six well trained paraplegic males volunteered for the study (age 25–35 years; body weight 69 ± 9 Kg).

Wheelchairs: Two light weight daily active use commercially available WHCHS were investigated. Type A, foldable. 13.95 Kg; type B, demountable. 13.35 Kg. The main differences in geometrical configuration were in the horizontal location of the wheel axle, in the seat surface height and in the back seat position.

Wheelchair ergometer: A WHCH roller ergometer (Sopur, Ergotronic mod.) was used. The ergometer consists of a platform with two rollers with negligible friction. where the distance covered and the speed are provided.

Protocol: 4 exercise bouts of 9 minutes each were required at submaximal speeds (2, 5, 7 and 9 Km/h) at 2 days interval while using wheelchair type A or B. In different days, the remaining wheelchair was used applying exactly the same protocol.

Variables investigated: Oxygen uptake (VO₂, ml O₂/min); pulmonary ventilation (VE, l/min) and heart rate (HR, beats/min) were determined at rest and at the last 2 min of each exercise bout by open circuit (Douglas bag) method. Venous blood was taken before and at the 5th min of recovery for lactic acid concentration (lA, mmol/l). From the ratio of VO₂ above resting divided by the speed and by the body plus WHCH weight, the energy cost of locomotion (C, ml O₂/Kg·m, i.e. the amount of O₂ required to cover 1 m distance per unit mass) was calculated at the various speeds.

Results and discussion

In fig. 1 are shown the individual values and the best fit regression lines of the net oxygen consumption observed at steady state during locomotion with both WHCH A and B. Even if the variability at the same speed is quite large due to the different ability of the subject to move the
whch, it clearly appears that at any given speed the oxygen consumption is much higher while propelling WHCH A than B (p<0.05).

![Fig. 1: Oxygen consumption values (above resting) are shown as a function of speed of locomotion using wheelchair A and B.](image)

The increase above resting of lactate concentration (∆[LA]) was practically negligible after the 9 min task at 2 km/h (fig. 2). However, with increasing the speed it changed significantly, reaching at about 9 km/h while using WHCH A, values up to about 8 mmol/l, not too far from the maximal value (about 10 mmol/l) that can be observed with upper limb maximal exercise. On the contrary, at the same speeds with WHCH B the values were significantly lower (5.5 mmol/l) at 9 km/h. Even if the anaerobic contribution to the total energy required is small, the large difference in LA concentration observed indicates that presumably WHCH A requires, at any given speed, a higher contribution of isometric effort in active muscles or a larger engaged muscle mass, particularly of the trunk.

![Fig. 2: Venous lactate concentrations above resting values are given as a function of speed of locomotion using wheelchair A and B.](image)

The energy cost of locomotion, C, is given for each individual subject in fig. 3. C increased linearly with speed with both WHCHS with similar slope. However, at any speed the values observed with WHCH A are much higher. The back extrapolation of the C vs speed lines, i.e., the intercepts of the two equations, may provide an estimate of the energy required in ml O₂/kg by the isometrically contracted muscles to maintain the posture and the equilibrium for the locomotion. This energy is much higher with WHCH A than B, showing that even small differences in geometric dimensions of the WHCHS affect enormously the posture.
Heart rate increased linearly with the speed for both the WHCHS (fig. 4) and was higher, even if not statistically, while using WHCH A than B, particularly at the higher speeds. At about 9 km/h HR reached maximal values during locomotion with WHCH A and was slightly lower with WHCH B.

Ventilation above resting is plotted as a function of the net oxygen consumption in fig. 5. For comparable oxygen uptake VE was similar for both WHCHS, thus showing that, even with different WHCHS, ventilation is dependent upon the energy metabolism.

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**Fig. 3:** Energy cost of locomotion (ml/O₂ above resting per Kg of body + wheelchair weight) as a function of speed using WHCH A and B. Back extrapolation to speed 0 of the lines provides an estimate of the oxygen required to maintain posture and equilibrium during locomotion.

**Fig. 4:** Heart rate changes during locomotion with the two WHCHS.

**Fig. 5:** Pulmonary ventilation as a function of net oxygen consumption during locomotion at speeds from 2 to 9 Km/h.
In table 1 is shown a comparison of the physiological variables observed during locomotion at 5 km/h with the two WHCHS. Values are means calculated on the basis of the relationships between each variable indicated vs speed, for each individual subject. Statistical analysis showed that, with the exception of HR, the difference is at p<0.05 level.

### At 5 km/h

<table>
<thead>
<tr>
<th></th>
<th>TYPE A</th>
<th>TYPE B</th>
<th>Δ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ (l/min)</td>
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<td>0.99</td>
<td>28</td>
</tr>
<tr>
<td>V̇E (l/min)</td>
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<td>25</td>
<td>52</td>
</tr>
<tr>
<td>HR (b/min)</td>
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<td>121</td>
<td>7</td>
</tr>
<tr>
<td>Δ [l]lAI (mmol/l)</td>
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<td>1.25</td>
<td>58</td>
</tr>
<tr>
<td>C (mlO₂/kgm)</td>
<td>0.13</td>
<td>0.09</td>
<td>44</td>
</tr>
</tbody>
</table>

Tab. 1: Mean values of oxygen consumption, pulmonary ventilation, heart rate, increase of lactate acid over resting and energy cost of locomotion observed at 5 km/h with WHCH type A and B.

Conclusions

The main results of this study concern the large difference existing in the energy cost of locomotion and in the lactate production in the same subject when two different wheelchairs, even if apparently similar, are used. In particular, the much higher cost and lactate production suggest that wheelchair design seems to affect the posture, the equilibrium and the limb and trunk movements in such a way that the metabolism of some muscle group requires a greater participation of anaerobic mechanism of energy supply, this leading to early onset of muscular fatigue. Further studies, in particular the combined biomechanical analysis of user and wheelchair during locomotion, are required to increase the optimum fitting of wheelchair–user interface.