A WHEELCHAIR ERGOMETER WITH A DEVICE FOR ISOKINETIC TORQUE MEASUREMENT

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ABSTRACT. A wheelchair ergometer has been developed for the study of wheelchair work. At each propulsion the peak torque can be examined, and there is an opportunity to directly study angular amplitude, power output, work, etc. The physical capacity of the subject as well as the importance of chair adjustments upon performance can be evaluated.

Keywords: wheelchair ergometer, isokinetic dynamometer.

Several reports exist in which physiological data concerning wheelchair work are presented (1, 2, 3, 6, 10). Various methods have been used for this purpose: (A) treadmill testing (3, 9, 12); (B) stationary wheelchairs connected to bicycle ergometers (1, 4); (C) stationary wheelchair connected to fly-wheel (11), and (D) wheelchair on rollers (8). These methods are insufficient since the single propulsions cannot be examined.

A factor of importance when evaluating different wheelchair is the actual power output. This factor can be calculated using the equation:

\[ P = F_v \cdot v \]

where

- \( P \) = actual power output
- \( F_v \) = resistance force
- \( v \) = velocity

\[ F_v = F_f + F_w + F_{\text{air}} + F_{\text{net}} \]

- \( F_f \) = internal friction
- \( F_{\text{air}} \) = air resistance
- \( F_w \) = acceleration force
- \( F_{\text{rolling}} \) = rolling resistance
- \( F_{\text{grav}} \) = gravitational component

If a fly-wheel is used, resistance force \( F_v \) can be provided by a gravitational force acting as friction and if \( r \) is the peripheral velocity of the wheel, the relation can be written:

\[ P = F_f \cdot v \]

Power output can also be expressed as the work per propulsion cycle multiplied by the frequency.

\[ P = A_v \cdot f \]

where

- \( A_v \) = mean work per cycle
- \( f \) = cycle frequency

\[ A_v = M \cdot \delta (Q) \]

where

- \( M \) = effective torque exerted on the propulsion system
- \( Q \) = the angle of the system

Previous studies have given the result that power output during wheelchair work is less than power output during arm cranking ergometry (11).

The estimation of physical work performance is usually done using maximal ergometry tests. The most common principle is based upon power output, oxygen uptake and changes in heart rate, i.e. physiological parameters. For patients needing a wheelchair for ambulation it is of importance to study their ability to maintain short term activity as well as submaximal performance. Likewise it is of importance to evaluate the patient’s capacity at short periods of wheelchair work, e.g. to overcome a slope or accelerate a heavy chair. The power output required can be calculated according to the equations shown above.

Work in conditions non-steady-state is difficult to study with conventional physiological methods.

The aim of the present study was to describe a wheelchair ergometer suitable for the intermittent character of wheelchair work.
METHODS AND MATERIAL

The wheelchair is set on the frame and attached firmly (Fig. 1). The wheels are connected to a common axis. The axis is connected to an isokinetic dynamometer (Cybex II). Chains and cog-wheels are used for power transfer. The gear ratio between drive-wheel and dynamometer axis is 1/1.

The recordings are made at different dynamometer angular velocities. We can adjust instruments from 15% to 100%. If the wheelchair drive wheel diameter is 24 inches those angular velocities correlate to 0.08–1.00 mph chair velocities.

The common axis can be disconnected from the dynamometer and connected to a fly-wheel. The power output when driving the wheelchair is then calculated as

\[ P_Y = F_v \cdot v \]

where

- \( F_v \) = breaking force
- \( v \) = fly-wheel peripheral speed

The torque and the angle is displayed as a function of time (Fig. 2). The variables which might be interesting are:
- peak torque
- mean torque
- angular displacement at propulsion
- peak power
- mean power
- total work of each propulsion
- time for withdrawal of hands for a new propulsion

In this study 5 disabled men and 4 male controls were examined. They were all recorded sitting in the same chair (Quick, Maratonproduktor, Sweden). Recordings were also made of isokinetic extension and flexion at the elbow at 30°/s and 180°/s angular velocity. This method was taken from the instructions given by the manufacturer (7).

RESULTS

The subjects had no difficulties accomplishing the test. Some important objections were found. The drive wheel had no inertia and stops immediately when the driver's hand leaves the rim. The hands then grip the rim which has no velocity. An impact thrust shows at the beginning at the isokinetically recorded propulsion (Fig. 2). All 5 disabled men complained that they were not used to the test wheelchair. However, it is possible to use the subject’s own chair.

The coefficient of variation was less than 10%. There was a tendency towards a greater angular displacement with each propulsion and a shorter withdrawal time for the rained disabled men. There was no difference regarding arm strength and peak torque between the two groups studied (Table I).

DISCUSSION

It is known that the gross mechanical efficiency of conventional hand rim wheelchairs rarely exceeds 10% (1). This is low when compared with for instance, the bicycle, suggesting a high internal waste of mechanical energy. Improvement of wheelchair energy utilization can be accomplished in three ways: (A) by improving the compatibility between the wheelchair and the subject by optimizing the “interface” between them; (B) by reducing power loss due to resistance to roll, internal friction, air resistance and gravitation; and (C) increasing the physical work capacity through training and technique.

This method provides the means to study every propulsion at different times. Since different chairs can be attached and adjusted it is possible to study the effects directly.

We believe that this type of wheelchair ergometer can provide further information concerning wheelchair ergometry. It can be a tool for feedback information to patients doing wheelchair exercise.

REFERENCES

METHODS AND MATERIAL

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The recordings are made at different dynamometer angular velocities. We can adjust instruments from 15°/s to 300°/s. If the wheelchair drive wheel diameter is 24 inches these angular velocities correlate to 0.88–1.60 mph chair velocities.

The common axis can be disconnected from the dynamometer and connected to a fly-wheel. The power output when driving the wheelchair is then calculated as

\[ P_W = F_v \cdot \omega \]

where

- \( F_v \) = force
- \( \omega \) = angular velocity

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**REFERENCES**


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**Table I. The results from the pilot study**

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>Disables</th>
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<tbody>
<tr>
<td>n</td>
<td>n=5</td>
<td>n=4</td>
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<tr>
<td>Isokinetic arm muscle-strength (Nm)</td>
<td></td>
<td></td>
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<tr>
<td>Flexion 30°/s</td>
<td>62 ± 13</td>
<td>54 ± 15</td>
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<tr>
<td>180°/s</td>
<td>51 ± 11</td>
<td>40 ± 15</td>
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<tr>
<td>Extension 30°/s</td>
<td>56 ± 18</td>
<td>56 ± 19</td>
</tr>
<tr>
<td>180°/s</td>
<td>51 ± 11</td>
<td>43 ± 14</td>
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**Table II. Isokinetic wheelchair torque (Nm)**

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<th>120°/s</th>
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<tr>
<td>65 ± 20</td>
<td>81 ± 28</td>
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ABSTRACT. Dynamic configurational changes in the rectus femoris muscle were examined using a real-time ultrasound sector scanner in ten normal subjects. The angle of passive knee flexion was varied as transverse ultrasound scanning was performed at the mid-transverse thigh. Configurational changes in the rectus femoris were computed from a traced outline of the muscle and the geometric center of the mass was calculated at all degrees of knee flexion. The geometric center of the mass varied with knee position. The anteroposterior dimensions and cross sectional areas of the rectus femoris and vastus intermedius remained constant, however, despite changes in knee position. The pattern of change observed was reproducible and reflects consistent changes in muscle configuration. The technique and instrumentation should have value for non-invasive dynamic and static observation of individual muscles.

Key words: ultrasonics; muscular atrophy; muscle degeneration; exostosis; lower thigh.

To our knowledge, dynamic relationships in a group of muscles have never been directly observed. Therapeutic approaches to the quadriceps muscles have been based on static observation and biomechanics modelling. Cadaver manipulations have led to definition of muscle group function, and inferences about dynamic force vectors in individual quadriceps components (4). Computed tomography has also been employed in the study of muscle anatomy (3) but once again this technique is one of static observation. More recently, ultrasound has proved to be a technically useful in describing the quadriceps mass (cross-sectional area) in normal thighs and in the presence of knee pathology (2, 6, 7). The effects of training have also been measured using ultrasound techniques (2). All these investigations have studied muscle with no observation of the configurational changes that accompany limb positioning or dynamic muscle activity.

Our study was designed to observe changes in the quadriceps muscles as the knee progressively flexes. The rectus femoris (RF) was chosen because of accessibility and the ease with which measurements can be made. The hypothesis on initiation of the study was that configurational changes in the RF occur depending on the angle of knee flexion.

METHODS

The thighs of ten subjects were examined using a real-time ultrasound sector scanner employing a 5 MHz transducer (Diasonics, Inc. Milpitas, California). The thighs were sonored in a transverse plane in the middle of a line between the lateral femoral epicondyle and the anterior superior iliac spine (Fig. 1). All examinations were recorded on 1/2 inch videotape for review and analysis. Ten male subjects with no history or evidence of back, hip, knee, or neuromuscular pathology were studied. Data from eight subjects are reported (Table 1) as two were excluded because the muscle echogeneity prevented delineation of fascial and bony landmarks. (One of the excluded subjects subsequently acknowledged a history of inflammatory bowel disease, inactive for ten years.)

The subjects were positioned seated with the hips flexed 40 degrees (Fig. 1). The thighs were examined individually and studied first at 90 degrees of knee flexion for a comparative baseline, then at 15, 30, and 60 degrees of knee flexion (Fig. 1). Three individual observations were made and recorded for each knee position. The related position was manually supported by the examiner at the given angle of flexion, avoiding any change that might result from muscle contraction. All ultrasound observations were made with the transducer submerged in a water-filled plastic sac over the thigh. The skin was coated with ultrasound gel (Fig. 2). The limb was passively positioned while the ultrasound study was conducted and video-recorded (1/2" U-Matic format).

DATA ANALYSIS

Ultrasound scans were reviewed by selecting single frames of video image and tracing the borders of the muscles as the screen with a graphics cursor (Micronetics, Inc. Indianapolis, IN). When the muscle anatomy was satisfactorily outlined, this outline was committed to memory with the midpoint of the femur marked and recorded to serve as an anatomic land-