Upsala J Med Sci 87: 223–233, 1982

Evaluation of a Dynamometer for Measurement of Isometric and Isokinetic Torques

Martin Ericsson[1], Kurt Johansson[2], Bengt Nordgren[1],
Lars-Olof Nordesjö[3] and Octavia Borges[1]

From the Department of Medical Rehabilitation[1], University Hospital, Uppsala, the Institute of Physics[2], Uppsala University, Uppsala and the Department of Clinical Physiology[3], Gävle Hospital, Gävle, Sweden

ABSTRACT

A modified version of the original Cybex II dynamometer with a temperature compensated strain gauge transducer has been evaluated. It was found that the calibration constant was dependent of the vertical load of the device. The ratio (k) between the applied and the recorded torque is angle independent during extension and k is equal to 1.18 and during flexion k is angle dependent and can be expressed as $k = -.0008\ \theta + 1.208$, where θ is the angle of flexion.

COMMENTS ON THE MODEL

It is important for clinicians involved in rehabilitating physically disabled patients to be able to measure changes in muscular performance and strength. The muscles are working both isometrically and dynamically. During the early 1960's, J J Perrine developed the concept of isokinetic exercise, i.e. dynamic movement with a constant speed, and it was first reported by Hislop and Perrine in 1967 (1).

The Cybex II dynamometer* has during some years been used clinically for measurement of isometric and isokinetic torques (2, 3, 4, 5). A modified version of the original device has recently been described (6). In the original device the torque was sensed via an oilcell. However, the output signal of the transducer was not linear, a factor which made a simple correction of the recorded data difficult. Therefore a new device has been developed which senses the torque by means of a strain gauge technique.**

The aim of this study has been to investigate the calibration conditions of the modified device in order to be able to present valid data.

Dynamometer

In this modified version of the original Cybex II dynamometer the hydraulic pressure gauge was replaced by a temperature compensated strain gauge transdu-

---

* Cybex Division of Lumex, 100 Spence Street, Bay Shore, N.Y. 11706

** Aeronautical Research Institute of Sweden cer (6).

A block diagram of the measuring system is presented in Figure 1.

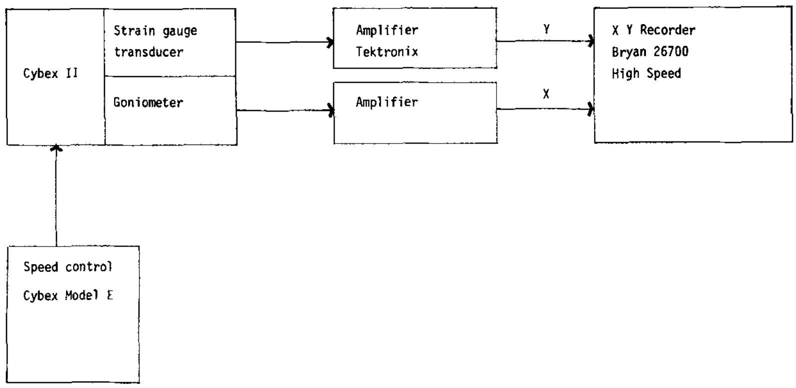

Fig. 1. Block diagram of the measuring system.

In the y-amplifier line there is a calibration signal, which corresponds to a torque equal to 50 Nm. Using this signal as calibration the result is denoted the recorded torque. In the present study the signal from the strain gauge transducer has been calibrated.

<u>Correction for the gravitational torque due to the mass of the lever arm and the limb</u>

The mechanical arrangement for measurement of the torque (M) is illustrated in Figure 2.

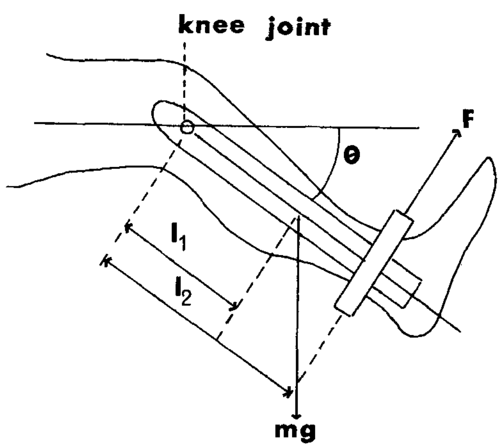

Fig. 2. Mechanical arrangement for measurement of the torque (M) during knee extension and flexion at a constant angular velocity.

F = the force produced by the limb.

l_1 = distance between the center of mass of the limb and lever arm and the axis of the knee joint.

l_2 = distance between the point where the lever arm is attached to the limb and to the axis of the knee joint.

θ = the flexion angle; $\theta = 0^{\circ}$ when the leg is fully extended.

mg = the weight of the lever arm and the limb.

Due to the force of gravitation on the lever arm and the limb a correction must be made for the gravitational torque (M_g)(7). Using the definitions in Figure 2 the formula for this correction is derived as follows:

$$M = F\, l_2 \qquad \text{(a)}$$

$$M_g = m\, g\, l_1 \cos\theta \qquad \text{(b)}$$

$$M = M_{reg} + M_g \qquad \text{extension of the knee joint} \qquad \text{(c)}$$

$$M = M_{reg} - M_g \qquad \text{flexion of the knee joint} \qquad \text{(d)}$$

The constant g is the gravitational acceleration and is equal to 9.81 m/s and M_{reg} is the recorded torque. The gravitational torque M_g is measured at an angle θ_o, i.e. $\theta_o = 0^{\circ}$ with the muscles of the limb relaxed. The result of this measurement is called M'_g.

The equation $$M_g = M'_g \frac{\cos\theta}{\cos\theta_o} \qquad \text{(e)}$$

is then used when calculating the torque of the lever arm and the limb as a function of the angle θ in the equations (c) and (d) above.

<u>Characteristics of the recorded torque</u>

The recorded torque of the knee joint for both extension and flexion is shown in Figures 3 and 4 in which the angular velocity is equal to 12 and 150 degrees/s, respectively. The torque of the gravitational force of the limb and lever arm is also presented in both figures and is denoted (a^3 in Fig. 3 and a^5 in Fig. 4).

Fig. 3. Recorded torque (M_{reg}) of a subject at 12°/s angular velocity.

a^1 = torque of a 5 kg weight hanging at the outer end of the lever arm.

a^2 = extension of the knee joint.

a^3 = gravitational torque of the limb and the lever arm at 12°/s.

a^4 = flexion of the knee joint.

Fig. 4. Recorded torque of a subject at 150°/s angular velocity.

a^5 and a^6 is the gravitational torque of the limb and the lever arm at 12^{0}/s and 150°/s respectively.

M_p = peak overshoot.

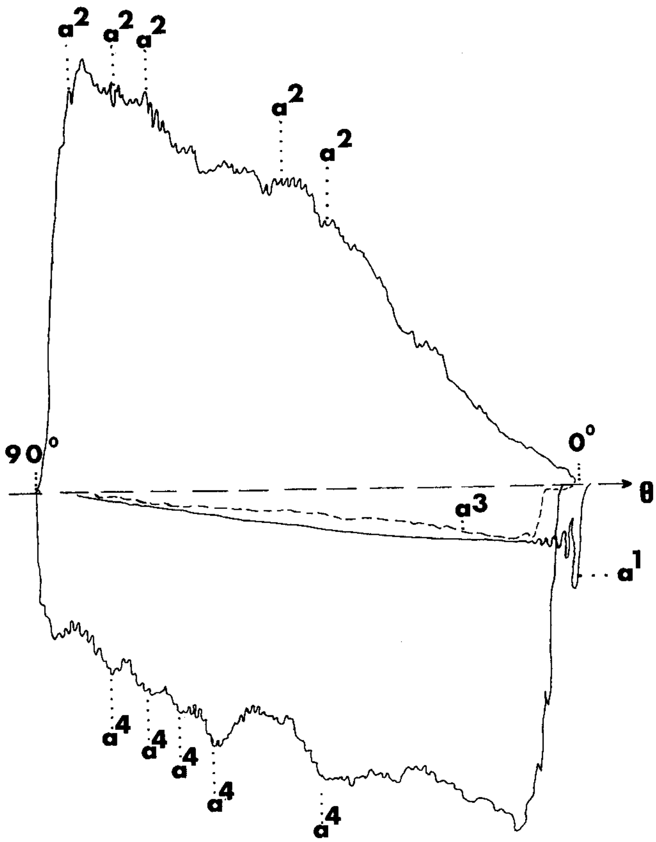

Fig. 3.

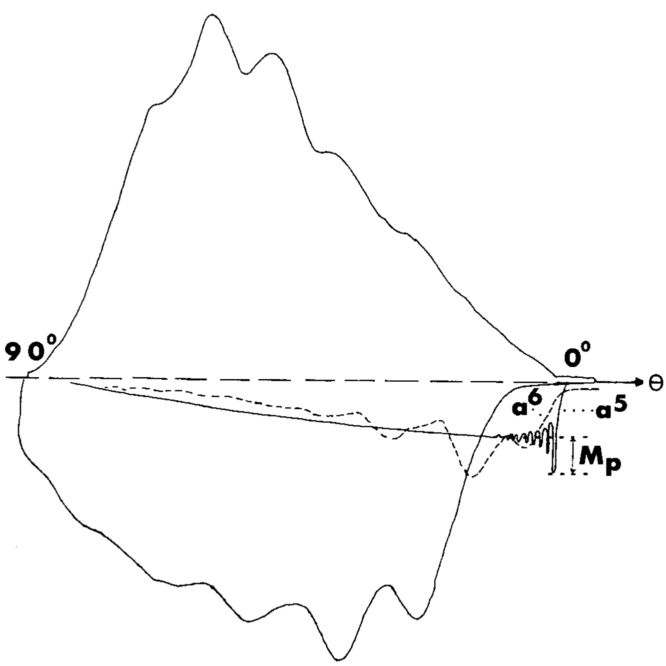

Fig. 4.

The recorded torque of a 5 kg weight hanging at the outer end of the lever arm is called a^1 in Figure 3. From that part of the figure it is concluded that there is a damped frequency of the control system equal to 10 ± 2 Hz. This frequency of the control system is also found i Figure 4. This oscillation is damped out after 4-5 periods. The same damped oscillations called a^2 in Figure 3 are also seen in the recorded torque of the knee joint both in extension and in flexion movement. When comparing the recordings a^1 and a^3 it is obvious that it is difficult to keep the muscles relaxed during the whole movement. The correction terms of the equations c and d should therefore be measured with the limb resting at a fixed angle (0^o). The gravitational torque M_g is then calculated using the equation e.

The recorded torque of the gravitational force of the lever arm and the limb are also shown in Figure 4. The angular speed is 12^o/s in the recording a^5 and 150^o/s in a^6. The peak overshoot (M_p) of the 10 Hz oscillation increases when the angular velocity is increased. The value of the second peak increases from 6 Nm at 12^o/s to 12 Nm at 150^o/s. These large peaks originating from the angular velocity control system of the Cybex II makes it difficult to calculate a valid maximum value of the recorded torque, which also has been pointed out by Winter et al (7). This difficulty is demonstrated in Figure 5, which is a calculated unit-step response of a third order control system. The applied torque M_a used in the calculation corresponds to the maximum torque, and the figure shows that the recorded torque of the system has a peak overshoot (M_p). Concequently the mean value curve can be used giving the applied torque.

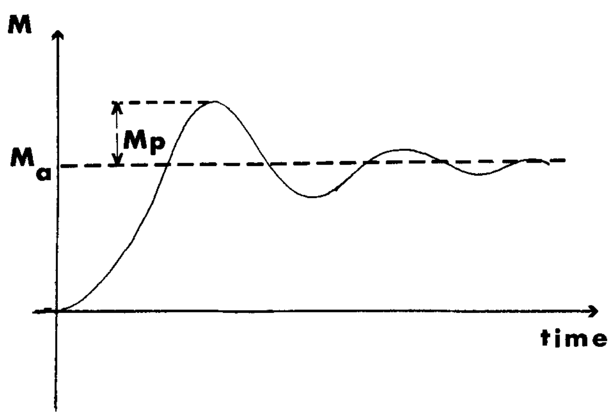

Fig. 5. A calculated unit-step response of a third order system. M_a = applied torque; M = recorded torque; M_p = peak overshoot.

This is also examplified in Figure 3 in the recording (a^1) as a dashed line.

There is also in Figure 3 an oscillation with a lower frequency which is equal to 1.6 $\pm$ 0.2 Hz. This frequency is probably not due to the control system but to the mechanical arrangement of the lever arm. The peaks of this frequency are marked with a^4 where they are most evident, but they can also be seen at some of the a^2-peaks. The same oscillation is also seen i Figures 7 and 8 where a constant torque is applied to the lever arm. It is therefore concluded that this frequency is not generated by the muscles.

Calibration

1. Extension of the knee joint

The total force acting on the strain gauges during the extension and flexion movement of the knee joint may influence the result of the measurement. In this presentation the extension movement this force is directed upwards and varies from 0 N to 350 N and in the flexion movement between 0 N to 300 N. A special calibration equipment was therefore constructed in order to obtain a similar vertical load as during an actual investigation of a subject. The experimental equipment for the calibration is shown schematically in Figures 6a and 6b. Two discs of aluminium with the radius equal to 0.15 m and 0.49 m respectively were used.

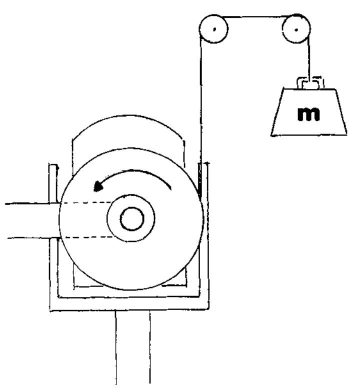

Fig. 6a

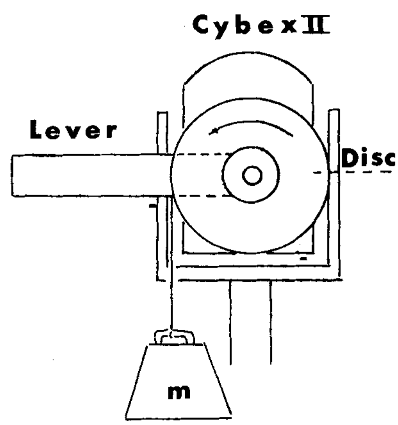

Fig. 6b

Fig. 6. Calibration set-up. The weight used to produce a constant torque is connected to the lever arm via a wire and a disc. The total force acting on the lever arm is equal to the difference between the weight of the disc and mass (m) in Figure 6a and to the sum of the masses in Figure 6b.

In the experiment shown in Figure 6a the vertical force acting on the axis of rotation is equal to the sum of the weight of the disc (25 kg or 3 kg) and the hanging weight (m). In Figure 6b the vertical force is equal to the difference between the weights of the two masses. The results of this experiment are presented in Figures 7 and 8 which corresponds to Figures 6b and 6a respectively

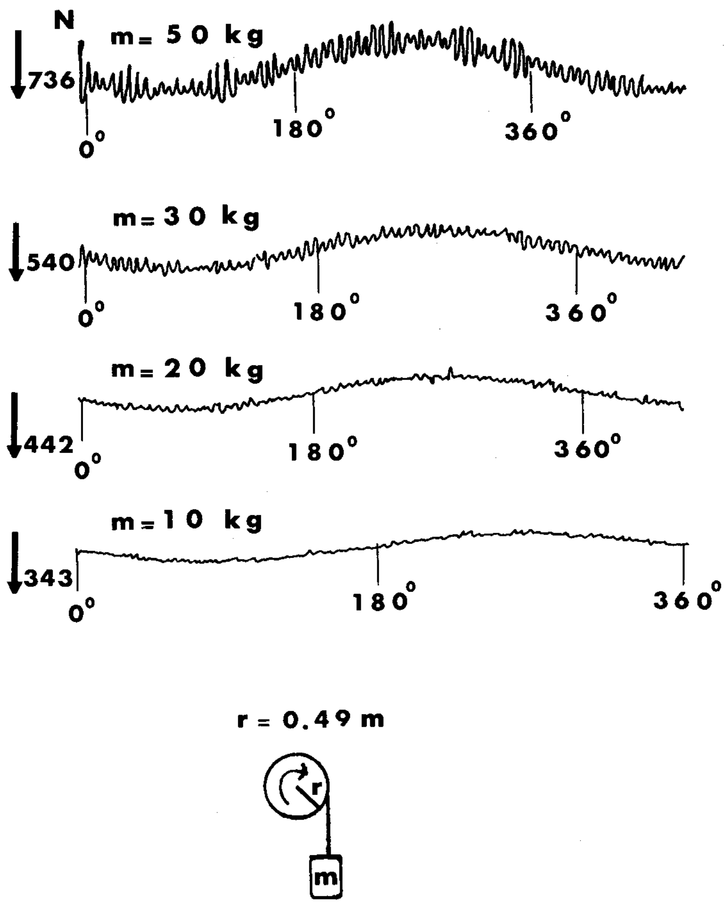

Fig. 7. Recorded torque for different weights (m). The calibration configuration is also shown. The total vertical force acting on the equipment is given to the left of the figure. Angular velocity = 12°/s.

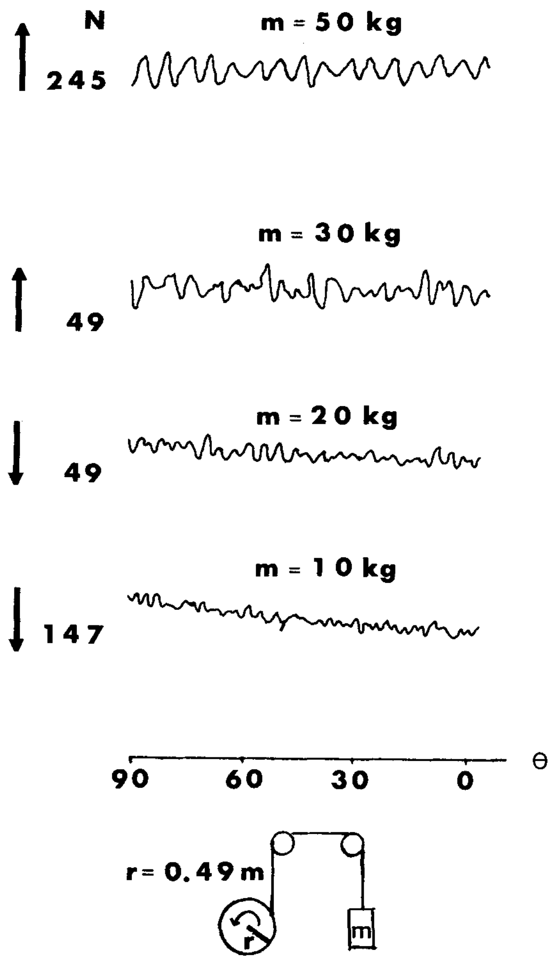

Fig. 8. Recorded torque for different weights (m). The calibration configuration is also shown. Angular velocity = $12^{o}/s$.

The recorded torque in Figure 7 shows an angular dependence and the calibration must therefore be made under similar conditions as during a clinical investigation. The curves in both figures for m = 50 kg indicate that as there is no angular dependence of the calibration constant in Figure 8, the calibration set-up in Figure 6a corresponds quite well to the clinical situation in the extension movement of the knee joint. The results from Figure 8 are given in Table I and the data corresponding within errors to a straight line. It is concluded from Table I that the recorded torque of the extension movement has to be multiplied by the calibration factor 1.18 in order to give the actual torque of a subject.

Angle θ^0	Applied torque (Nm)			
	48	96	144	240
	Recorded torque (Nm)			
90	41	82	123	213
70	38	80	123	213
50	36	79	123	213
30	35	78	123	213
10	34	78	123	213

Table I. Recorded torque from the calibration according to the set-up in Fig. 6a (extension). The radium of the disc equals 0.49 m.

2. Flexion of the knee joint

The calibration set-up for the flexion movement is illustrated in Figure 9.

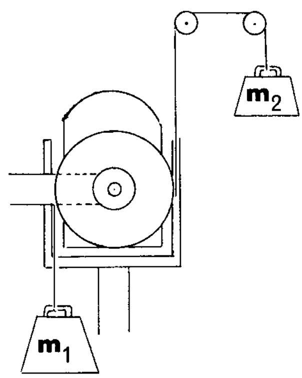

Fig. 9. Calibration set-up corresponding to the flexion movement of the knee joint. The radius of the disc is 0.15 m.

This was used to produce a vertical downward force corresponding to flexion of the knee joint. The downward vertical force is the sum of m_1 and the weight of the wheel (3 kg) minus the upward vertical force generated by m_2.

The recorded torques for different vertical loads of the rotation axis are shown in Figure 10.

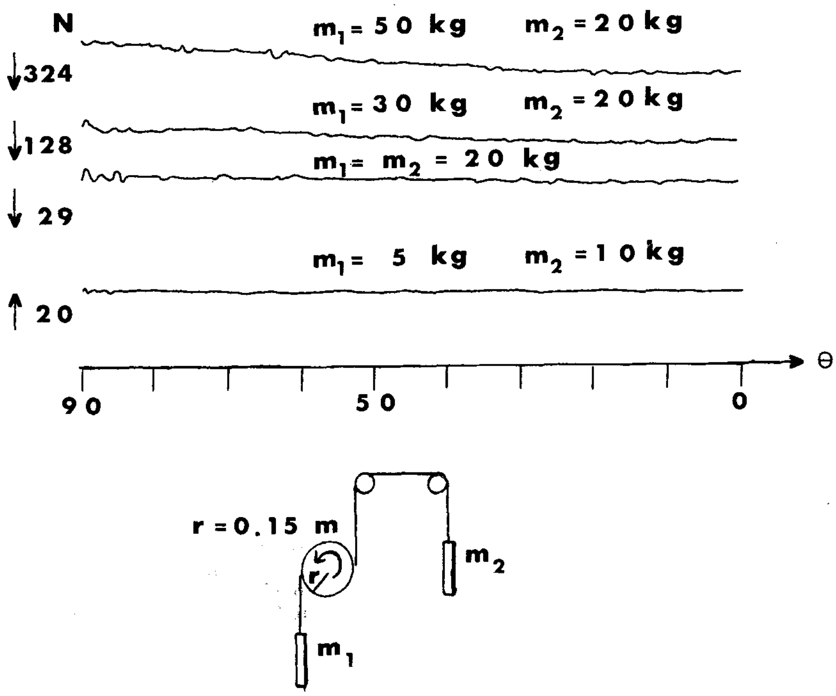

Fig. 10. Recorded torque for different weights m_1 and m_2. The calibration configuration is also shown. The total vertical force acting on the equipment is given to the left of the figure. Angular velocity = $12^{\circ}/s$.

The conclusion from Figure 10 in this case is that the calibration constant is angular dependent. The result of the calculation of the constant where the data in Figure 10 was used is shown in Figure 11.

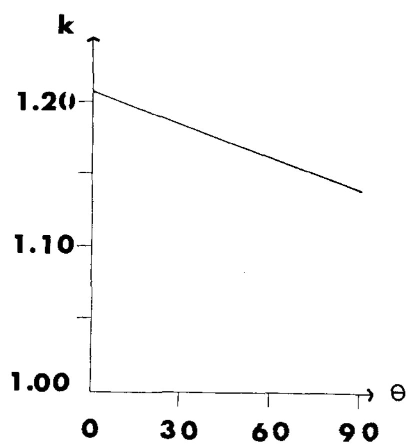

Fig. 11. Calibration constant (k) for flexion as a function of the angle θ. k = applied torque divided by recorded torque.

The vertical axis k is equal to the applied torque divided by the recorded one. The calibration constant is expressed in numerical values as $k = -0.0008\,\theta + 1.208$, where the angle of flexion of the knee joint defined in Figure 2.

CONCLUSION

It was found in this study that the calibration constant (k) for the dynamometer used in our laboratory differs between extension and flexion movement of the knee joint. The constant is defined as the ratio between the applied and recorded torque. During extension k is angle independent and equals 1.18, $-.0008\,\theta + 1.208$, where θ is the angle of flexion of the knee joint.

ACKNOWLEDGEMENT

This work was supported by the Swedish Medical Research Council Grant No. 1156 (M.E.)

REFERENCES

1. Hislop, H.J. and Perrine, J.J.: The isokinetic concept of exercise. J Am Phys Ther Assoc 47:114-117, 1967.
2. Murray, P., Gardner, G.M., Mollinger, L.A. and Sepic, S.B.: Strength of isometric and isokinetic contractions. Knee muscles of men aged 20-86. Phys Ther 60-412, 1980.
3. Goslin, B.R. and Charteries, J.: Isokinetic dynamometry: Normative data for clinical use in lower extremity (knee) cases. Scand J Rehab Med 11:105-109, 1979.
4. Knapik, J.J. and Ramos, M.U.: Isokinetic and isometric torque relationships in the human body. Arch Phys Med Rehab 60-64, 1980.
5. Scudder, G.N.: Torque curves produced at the knee during isometric and isokinetic exercise. Arch Phys Med Rehab 61-68, 1980.
6. Gransberg, L., Knutsson, E. and Litton, J.-E.: A computer programmed system for the analysis of active and passive isokinetic movements. Frontiers of Engineering in Health Care 13.3.1, 1980.
7. Winter, D.A., Wells, R.P. and Orr, G.W.: Errors in the use of isokinetic dynamometers. Eur J Appl Physiol 46:397-408, 1981.

Address for reprints:

Martin Ericsson, M.D.
Dept of Rehab Med
University Hospital
S-750 14 Uppsala
Sweden