Handgrip dynamometry, Cybex measurements and lean mass as markers of the ageing of muscle function

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Isometric handgrip force, isokinetic knee flexion and extension torque, and anthropometric data were obtained on 67 older men and women (ranging in age from 45 to 75 years, mean 59.7 years). Hydrostatic and skinfold estimates of lean body mass were quite closely correlated with each other in this sample ($r = 0.93$). Handgrip force, isokinetic knee flexion and extension torque, and lean mass all decreased by 6–8% per decade over the age span examined, although in the men the loss was most marked in terms of handgrip and lean mass, whereas in the women the loss of torque in the knee muscles was dominant. Because of these differences, the handgrip data were only weakly correlated with the isokinetic strength measurements ($r = 0.22$), and the isokinetic data were more strongly related to lean body mass and body mass. The optimum equation for a field prediction of isokinetic strength in this age group (a combination of age, sex, age–sex interaction and lean body mass) has an error approaching 25%, with a multiple r^2 of 0.37, and a standard error of the estimate (s.e.e.) of 24.5%. It is concluded that handgrip data and slow isokinetic torque measurements evaluate relatively independent aspects of the ageing of muscular function.

Keywords: Ageing, isometric handgrip force, isokinetic strength, knee flexion, knee extension, lean body mass

For reasons of cost and convenience, the Stoelting handgrip dynamometer (Type TKK Model 1201 Dynamometer, C. H. Stoelting, Chicago, Illinois, USA) has been widely used in field surveys of both children and adults[1]. Some observers have found correlations as high as 0.80 between such data and overall measures of isometric strength[2,3] or isokinetic torque[4]. However, the muscles involved in the isometric gripping movement are relatively small, and it seems likely that the ability to generalize from such findings might be reduced in an older population where a selective loss of lean tissue is likely to have occurred. Accordingly, we have examined the relationships between isometric handgrip force and isokinetic measurements of knee extension and flexion torque at three slow speeds of rotation,

comparing the rate of ageing in both datasets with estimates of overall lean mass derived from hydrostatic and skinfold estimates of body fat.

Methods

Subjects and experimental plan

The subjects were 33 women and 34 men aged 45–74 years, all clinically healthy and only moderately active, but nevertheless volunteers for an experimental programme that included subsequent assignment in random fashion to weekly light exercise classes, classes in health education, or a control group. Recruits were drawn from the university community in accordance with a plan approved by the University Committee on Human Experimentation. Measurements of isometric handgrip force, isokinetic knee extension and knee flexion torque, and body composition were completed before beginning the programme (Table 1).

Isometric handgrip force

All measurements were made with a Stoelting handgrip dynamometer, individually adjusted for the size of the subject's handgrip. Two definitive measurements were made on each hand, the peak force (newtons) being recorded in each case.

Isokinetic torque

All measurements were made with a Cybex II isokinetic dynamometer (Lumex Corporation, New York, USA), using the right leg. After careful alignment of the knee joint with the axis of the apparatus, three different angular velocities of knee extension and knee flexion were presented to the subjects in a randomized order: 18, 30 and $60° \text{s}^{-1}$ ($0.32–1.05 \text{ rad s}^{-1}$). Three measurements were made at each of the three angular velocities commencing with the knee flexed at 90°. To obtain readings free of distortion, the damping selection switch was set to zero and torques were recorded 30° after the initiation of contraction. Forces were thus recorded at an angle of 60° from the vertical during extension, while during flexion forces were recorded at an angle of 120°. As can be seen from Figure 1, this approach allows the recording of torque without application of

Table 1. Physical characteristics of subjects

Variable	Women (n=33)†	Men (n=34)†	Total (n=67)†
Age (years)	61.5(10.7)	57.5(8.5)	59.7(9.8)
Height (cm)	160.1(7.3)	173.8(5.9)	167.3(42.8)
Body mass (kg)	65.3(11.4)	74.7(11.9)	69.6(12.5)
Skinfolds (<4, mm)	112.1(35.6)	77.7(23.6)	94.1(34.4)
Hydrostatic body fat (%)	39.3(7.7)	27.8(6.0)	33.4(9.0)
Lean body mass (kg)	38.4(5.7)	55.0(7.2)	47.0(10.6)
Handgrip force			
R (N)	325(116)	485(89)***	404(131)
L (N)	297(91)	451(82)***	372(116)
R + L (N)	622(205)	936(167)***	776(244)
Isokinetic knee flexion torque			
$18°\,s^{-1}$ (Nm)	63.3(17.5)	75.2(23.7)*	69.1(21.5)
$30°\,s^{-1}$ (Nm)	63.1(18.4)	79.7(24.1)**	71.3(22.8)
$60°\,s^{-1}$ (Nm)	60.8(19.9)	76.8(23.2)**	68.7(22.9)
Isokinetic knee extension torque			
$18°\,s^{-1}$ (Nm)	50.0(13.5)	63.2(20.1)**	56.5(18.2)
$30°\,s^{-1}$ (Nm)	49.5(13.6)	64.5(19.9)***	56.9(18.5)
$60°\,s^{-1}$ (Nm)	48.3(13.7)	62.5(19.5)***	55.3(18.1)

Values are mean(s.d.)
† Because of missing data, some totals are marginally smaller
Significance of sex differences: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$

external damping. At the slower speeds, the contraction was sustained for longer before measuring the torque. This method of assessment thus had the interesting effect of equalizing the recorded torques relative to speed of rotation over the range $18–60°\,s^{-1}$. No gravitational correction was applied to the torque data, because methods of applying such corrections remain controversial. Gravitational effects can be important during light contractions at low angular velocities[5], adding major distortions to the early part of the torque record. However, such effects are much smaller under the conditions adopted in the present experiment (maximal contractions, with measurement late in the contraction cycle). The likely effect would be some overestimate of extensor torque (<25%) and some underestimate of flexor torque (<25%); given that the subjects were relatively homogeneous, such systematic errors would also be relatively constant from one person to another.
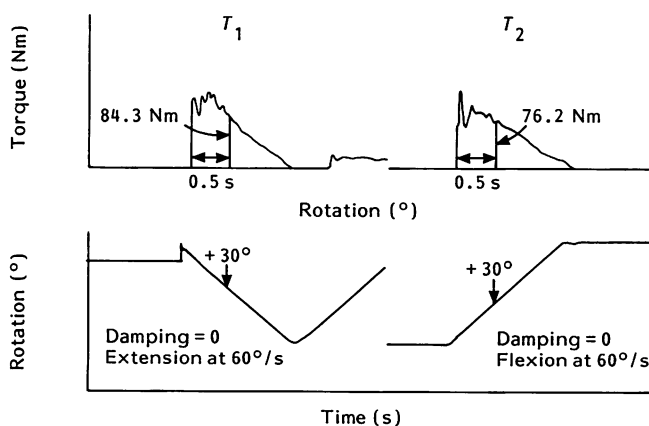

Figure 1. The recording of isokinetic torque 30° after the initiation of knee flexion or extension. In both cases, the force can be recorded without interference from oscillations at this stage. Data for 60-year-old man with isokinetic device recording flexion or extension force at $60°\,s^{-1}$

Body composition

Height and body mass were recorded by standard anthropometric techniques[6]. Body density was determined by hydrostatic weighing, residual volume being determined by nitrogen dilution, and the percentage of body fat was predicted according to the equations of Siri[7]. Biceps, triceps, subscapular and suprailiac skinfold thicknesses were also measured on the right side of the body, using Lange skinfold calipers, and a second estimate of body density and thus body fat was made using the equations of Durnin and Womersley[8]. The lean body mass was then calculated from total body mass and from each of the two estimates of percentage body fat.

Statistical analysis

The statistical analysis included descriptive variables (mean(s.d.)), the correlation of individual variables with isometric force, isokinetic torque and lean body mass, and a step-down multiple regression for the prediction of isokinetic torque eliminating all regression coefficients with a P value > 0.1.

Results and discussion

Descriptive variables

The mean age of the sample was a little under 60 years. Both women and men were a little taller than subjects of comparable age who were tested in the Canada Fitness Survey (CFS), the mean heights being 157.5 and 171.0 cm, respectively[1,9]. This probably reflects the fact that they were drawn from a group of somewhat above average socioeconomic status. The body mass of the women was close to the CFS age-matched mean of 64.1 kg, while the men were a little lighter than the CFS sample (mean 77.4 kg).

It is recognized that the hydrostatic weighing technique tends to be compromised by osteoporosis

in older individuals, while the validity of skinfold estimates of body fat deteriorates because of alterations in the proportions of deep and superficial fat[10]. Nevertheless, in the present sample, the two techniques gave similar results (respective mean(s.d.) percentage body fat 33.4(9.0) and 36.0(9.0), coefficient of correlation 0.78; mean lean body mass 44.5(10.2) and 47.0(10.6) kg, coefficient of correlation 0.93).

Both the summated skinfolds and the estimates of percentage body fat were substantially above the CFS levels (CFS readings for subjects over 60 years: women, 67.2 mm, 29.9% fat; men 50.8 mm, 23.2% fat). This confirms individual comments that one factor motivating volunteers for the study was a wish to reduce body fat.

Given a normal or low normal body mass, and a high percentage of body fat, it is plain that the sample had a less than average lean body mass for their age. Nevertheless, the isometric handgrip forces exceeded the CFS means of 425 N in the men and 253 N in the women[1].

Because of the measuring technique used, isokinetic torque values were of the same general order at all three speeds, with a difference of some 20% between scores for the men and the women. A similar difference between flexion and extension scores must be interpreted with caution because of the gravitational effects noted under methodology. Readings at $60°\,s^{-1}$ were somewhat smaller than the 89 and 61 Nm reported by Laforest et al.[11] for extension and flexion movements, respectively, in sedentary 65-year-old men and women.

Individual correlations

The similarity of results for the three flexion and three extension torques speaks against any substantial distortion of results by gravitational effects. Detailed results are considered simply for the movement of flexion at $60°\,s^{-1}$ (Table 2). As might be expected from ergonomic experience with younger adults[12, 13], the largest coefficients of correlation were with lean body mass and total body mass. Both of these measurements showed substantially larger coefficients for isometric handgrip force ($r = 0.70$, 0.54) than for isokinetic flexion torque ($r = 0.40$, 0.36).

Since estimates of lean body mass were obtained by both hydrostatic weighing and by skinfold measurement, it was possible to assess the validity of the two estimates relative to handgrip force and isokinetic torque measurements. Coefficients of correlation were of a similar order for hydrostatic ($r = 0.71$, 0.70) and for skinfold ($r = 0.31$, 0.40) estimates. The hydrostatic estimate has been used in subsequent calculations.

Prediction of isokinetic torque

Data for the prediction of isokinetic torque scores were entered into multiple regression equations of the type:

Cybex torque = a (sex) + b (lean mass) + c (summed grip) + d

Table 2. Individual variables and products significantly correlated with isokinetic flexion torque at $60°\,s^{-1}$

Variable	Coefficient of correlation	P
Height	0.26	0.037
Body mass	0.36	0.007
Hydrostatic body fat	−0.20	0.088
Lean body mass	0.40	0.003
Sum of grip forces	0.22	0.067
Left grip force	0.22	0.065
Right grip force	0.22	0.073
Age	−0.25	0.042
Age^2	−0.25	0.043
Sex	0.23	0.056
Sex/skinfolds	0.35	0.009
Sex/body mass	0.31	0.018
Sex/lean mass	0.30	0.019
Sex/right + left grip	0.23	0.063
Sex/height	0.24	0.050
Age/body fat	−0.29	0.022
Age/lean mass	0.28	0.029

using all of the measured variables as initial entry data. An example of the process for isokinetic flexion at $60°\,s^{-1}$ is given in Table 3, and the general similarity of responses under the other conditions of measurement is illustrated in Table 4.

The primary variables for the prediction of isokinetic force at $60°\,s^{-1}$ were, in order of statistical significance, the sex of the individual (F=1, M=2), the product of sex and age, the age, and the lean body mass. When these variables had been entered, the remaining items were no longer statistically significant, the equation becoming:

Torque (Nm) = −122.6 (sex) −2.69 (age) +1.91 (age–sex) + 1.17 (lean mass) +187.9 (s.e.e. 16.8)

The multiple correlation coefficient was 0.61, showing that these variables together accounted for some 37% of the variance in the isokinetic data, the standard error of the estimate amounting to 24.5%. It is perhaps worth stressing that the prediction is only a little more precise than that derived from sex, age, age–sex interaction and total body mass:

Torque (Nm) = −106.5 (sex) −2.92 (age) +1.89 (age–sex) +0.51 (mass) +196.5 ($r = 0.59$, s.e.e 16.96, 24.7%)

Table 3. Multiple regression equation for prediction of isokinetic flexion torque at $60°\,s^{-1}$

Variable	β-weight*	Significance
Sex (F=1, M=2)	−122.6(33.6)	<0.0007
Sex–age	1.91(0.53)	<0.0009
Age (years)	−2.69(0.76)	<0.0010
Lean mass (kg)	1.17(0.39)	<0.005
Constant	187.9(47.0)	<0.0003

*Values are mean(s.d.); s.e.e. 16.8, Multiple $r = 0.61$, $r^2 = 0.37$
Variables rejected: age^2, height, body mass, left handgrip force, right handgrip force, summed grip force, skinfolds, body fat

Table 4. Statistical significance of multiple regression analyses for prediction of isokinetic flexion (F) and extension (E) torque

Variable	$18°s^{-1}$		$30°s^{-1}$		$60°s^{-1}$	
	F	E	F	E	F	E
Sex	−0.050	n.s.	−0.019	n.s.	−0.0007	−0.056
Age	−0.077	−0.011	−0.025	−0.005	−0.0010	−0.004
Age−sex	+0.076	+0.087	+0.028	+0.018	+0.0009	+0.025
Lean mass	+0.025	n.s.	+0.008	n.s.	+0.0047	+0.160
Grip sum	n.s.	n.s.	n.s.	n.s.	n.s.	+0.059
Grip left	n.s.	n.s.	n.s.	n.s.	n.s.	−0.075
r^2	0.19	0.12	0.28	0.18	0.37	0.33
s.e.e.	18.7	14.8	17.4	14.7	16.8	13.3

n.s. not significant

Kofsky et al.[4] have explored the possibility of making field predictions of isokinetic strength in patients in wheelchairs. They were able to achieve a correlation coefficient of 0.82 between isometric and isokinetic data, the standard error of the estimate being 12.9%; this was partly because of a larger spread in their data, in part because higher speeds of movement were used, and in part because they measured the maximum isometric force in six muscle groups.

Effects of age

Given that there is some loss of lean tissue with ageing (about 2.5% decrease per decade in the present sample), a change in gravitational correction could have increased the uncorrected flexor torque by up to 0.6% per decade, with an opposite effect in extension. When considered in isolation, age was negatively related to the uncorrected isokinetic force in the women ($r = -0.58$, $P = 0.0013$), but had no significant influence on data in the men ($r = 0.24$, $P = 0.25$); this presumably reflects the fact that the men reported higher levels of daily physical activity than the women. The mean(s.e.m.) loss of torque for the sample as a whole was 17.7(8.1)% over the age range 45–75 years ($r = -0.29$, $P = 0.03$), a much larger change than could arise from changes in gravitational effects. The pooled data for the men and women showed significant linear and quadratic relationships of age to isokinetic force. The sex of the subject also influenced isokinetic force, most obviously as cross products with skinfolds, body mass and lean mass, implying that each of the latter variables had a different influence on isokinetic strength in the two sexes. Likewise, age/body fat and age/lean mass had significant cross products, suggesting that the influence of lean mass upon isokinetic force varied with age (Table 2).

The summed handgrip force had a significant negative relationship to age in the men ($P < 0.0005$), but not in the women, the slope for the group as a whole being $-6.67(3.53)$ N year^{-1}, corresponding to a loss of 22.8% over the age span 45–75 years.

The loss of lean body mass was also significant in the men ($P = 0.02$) but not in the women, the mean effect for the group as a whole being a loss of 0.45(0.15) kg year^{-1}, a loss of 26.2% over the age span 45–75 years.

There is little argument that the muscles generally become weaker with ageing[1, 14–21], although biopsy studies have generally been on the leg muscles. It is less certain that the muscles involved in an isometric handgrip age at the same rate as the isokinetic function of the leg; indeed, our data suggest a sex difference in the ageing of these two datasets, with the handgrip force running more in parallel with the loss of lean tissue. At all of the speeds of rotation tested, ageing led to a linear decline of isokinetic force at the knee in the female subjects; moreover, after allowance for the linear age term, there was no significant quadratic term over the age range examined (Table 4).

Averaging across the sexes, the loss of isokinetic torque amounted to about 5.9% per decade, a loss that is similar to the 6% per decade reported by Laforest et al.[10] at $60°s^{-1}$; at the same time there was a 7.6% per decade loss of handgrip force and an 8.7% loss of lean body mass. Even if further ageing does not introduce a quadratic term, such a rate of loss seems likely to have an important impact upon function in later old age, pointing to the need for training programmes to maintain and restore muscle strength.

Sex differences

The effects of sex were shown in our sample through a negative sex coefficient and a positive sex–age interaction (Table 3), implying that the difference in isokinetic force between men and women increased with age. The age-related decline of torque was due entirely to the female subjects.

These findings contrast with those of Laforest et al.[11], who found no age–sex interaction when comparing the isokinetic strength of young (25–30-year-old) and elderly (65-year-old) men and women. Like Laforest et al.[11], we used a relatively small non-random sample, and the difference of results is likely to be because of recruiting bias. Laforest et al.[11] attempted to minimize sex differences of activity patterns by testing continuing tennis players and continuing sedentary subjects of each sex. In our

sample, the older male recruits had a moderate level of habitual activity, and a number were interested in restoring their cardiorespiratory fitness by jogging, whereas the women were less active and were interested primarily in the control of body fat.

Generality of measures of muscle function

Lean body mass was positively correlated with isokinetic force, and in five of the six analyses there was no independent contribution from isometric handgrip force once lean mass had been included in the prediction equation. Indeed, even the simple correlation between isometric handgrip force and isokinetic strength was relatively weak. It thus appears that the two tests measure different attributes in this age group.

The isometric handgrip force has a larger correlation with lean mass than does the knee torque, and it may thus be a more generalizable measure of residual muscle function. However, whether generalizable or not, handgrip force remains very important to the activities of daily living in old age. Lean body mass provides a simpler and more valid field measure of isokinetic knee torque than does the estimation of maximal isometric handgrip force. However, even the optimal prediction equation based upon age, sex and lean mass has an error of almost 25% at slow speeds of contraction.

Conclusions

In the present sample of relatively sedentary older men and women, muscle function declined by 6-8% per decade. There is only a limited correlation between losses of isometric handgrip force (seen mainly in the men) and the isokinetic torque of knee flexion and extension (seen mainly in the women). Although the isometric handgrip measurements are relatively easy to make, they measure a different attribute than isokinetic torque. Rough estimates of the latter can be based upon age, sex and lean body mass, but the error of such predictions is likely to approach 25% in older individuals.

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