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ISOMETRIC AND ISOKINETIC KNEE EXTENSION AND FLEXION TORQUE IN MEN AND WOMEN AGED 20–70

Octavia Borges

Departments of Rehabilitation Medicine and Clinical Physiology, University Hospital, Uppsala, Sweden

ABSTRACT. An investigation was made of the influence of age and sex on peak muscle torque in knee extension and flexion during maximal isokinetic and isometric contraction. The study was performed on both legs of 139 clinically healthy men and 141 clinically healthy women aged 20, 30, 40, 50, 60 or 70 years. Maximum knee extension and flexion muscle torque (Newtonmetre, Nm) was measured isokinetically at various angles of velocity (12, 90 and 150 degrees/s) and isometrically under standardized conditions (Cybex II). No significant differences were found between the right and the left leg in the whole material. Muscle torque was higher in men than in women in all age groups ($p<0.001$). Both isokinetic and isometric torque decreased with age in both sexes. Isokinetic torque decreased significantly ($p<0.05$) between 20 and 30 years of age in men and between 40 and 50 years of age in women (at all velocities studied; $p<0.05$). A significant decrease ($p<0.05$) was found between the ages of 60 and 70 years in both sexes. Maximum isometric torque showed a significant decrease ($p<0.05$) between 60 and 70 years in men and women. There were no significant differences in isokinetic or isometric torque between moderately active and inactive men or women. Significant correlations were found between muscle torque and body weight, height and body surface area.

Key words: muscle strength, isometric, isokinetic, human skeletal muscle, young, elderly.

During the past ten years the number of studies of isometric and, especially isokinetic muscle torque has increased considerably. As nowadays a growing proportion of the population lives longer and remains physically active for a longer time, it is becoming of increasing importance to obtain information on changes in muscle torque in relation to the ageing process in men and women. The availability of age-related values of muscle torque is important when estimating the muscular performance in patients with impaired locomotor function or in training programmes for healthy subjects.

The relation between muscle torque and age has been investigated by a number of authors: Isometric knee extension was studied by Asmussen & Heeboll-Nielssen (7, 8) in both sexes, in the age range 15 to 65 in men and 15 to 55 in women. Larsson et al. measured both isometric and isokinetic strength in males between 11 and 70 years of age (19). Aniansson et al. measured both isometric and isokinetic strength in 70-year-old (1) and in 75-year-old (3) men and women. Murray et al. measured isometric and isokinetic strength in men aged 20 to 86 years (22) and in 72 healthy women aged 20 to 86 years (23). In all the above studies a decrease in muscle torque was found with increasing age.

The decrease in muscle torque with age is dependent on a number of factors: reduced fibre areas in old age (14, 19, 31), a loss of the total number of muscle fibres between 30 and 70 years of age (15, 21), changes in the neuromuscular system with a progressive decrease in the trophic function of the nerve cell in old age (16). These factors may in part explain the reduction in muscle mass and muscle torque that occurs in the ageing process.

Isometric torque is necessary for the maintenance of posture, and isokinetic torque of different velocities is necessary for movements (walking, running). In the present study measurements of knee extension and flexion torques were made in groups of men and women 20–70 years old. Both the right and left legs were studied. The results were related to a number of factors, including the level of physical activity of the subjects.

SUBJECTS

Information on the study and questionnaires were sent to 1 319 persons of ages 20, 30, 40, 50, 60 or 70 years randomly selected from the register of the Uppsala Office of Statistics. All of them were residents of Uppsala and its vicinity. The following variables were covered by the questionnaire: age, sex, body weight and height, physical activity level, dominant side (right- or left-handed) and present or past illness. It was answered by 763 persons, 483 of whom were

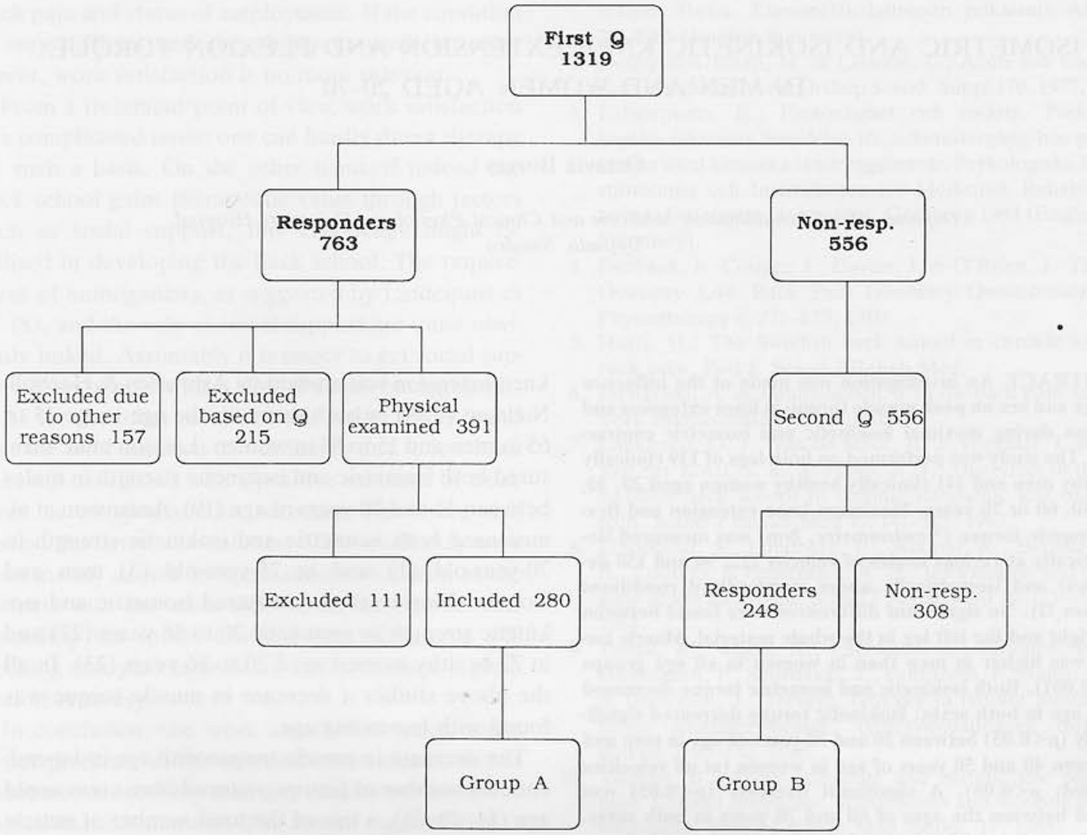

Fig. 1. Questionnaire (*Q*) respondents and non-respondents in groups A and B.

Table I. *Characteristics of the volunteer subjects*

Values are given as mean ($\bar{X}$) and standard deviation (SD). Group A participated and Group B did not participate in muscle torque testing. BSA = body surface area (according to Dubois)

				Weight (kg)				Height (cm)			
		n		A		B		A		B	
Age (yrs)	Sex	A	B	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
20	Men	27	23	75	10	72	9	180	6	180	5
	women	26	24	61	7	62	7	168	6	169	4
30	Men	26	18	76	15	75	14	178	5	179	7
	Women	30	21	60	7	60	6	166	5	166	6
40	Men	23	25	78	10	78	15	178	6	176	6
	Women	30	29	66	10	63	13	166	6	164	4
50	Men	21	20	80	15	77	10	177	6	175	7
	Women	17	18	67	9	65	10	164	5	164	6
60	Men	21	23	83	13	76	12	175	7	177	6
	Women	17	16	63	7	67	11	161	5	164	5
70	Men	21	16	76	10	79	9	176	6	175	7
	Women	21	15	66	10	62	10	162	5	162	5

excluded because of illnesses or other reasons, to be further described.

The remaining group available for study thus consisted of 280 clinically healthy subjects, 139 men and 141 women. The number of subjects in each age group varied from 17 to 30 men or women.

Physical activity

The subjects of this study were not involved in any systematic physical training for competitive sports. On the basis of their questionnaire answers concerning their physical activities over the last five years, they were divided into two groups: moderately active and inactive according to Saltin & Grimby (25). Those who engaged in some physical activity (e.g. swimming, bowling, jogging, bicycling, or gymnastics for retired persons) at least more than once a week were classified as moderately active. This group included subjects whose work was physically very demanding (bricklayers, lumberjacks, etc). Subjects with no physical activity other than normal daily living and with mainly sedentary activities such as reading, watching television, etc, were classified as inactive.

Analysis of the drop-out rate

Out of the 763 responders, 215 were excluded from the study because of different illnesses mentioned in their replies, e.g. injuries to the knee, decreased mobility of the knee and traumatic or inflammatory arthritis affecting the general state of health and/or the muscle strength of the lower limb. Other reasons for non-participation were unwillingness to take part (40 subjects), a change of address to another part of the country (15 subjects), or full-time work making attendance at the muscle test impossible (36 subjects). Two subjects had died and 64 subjects could not be reached.

Appointment notes were posted to the remaining 391 respondents for an initial physical and neurological examination with routine blood and urine tests at the Department of Rehabilitation Medicine of the University Hospital, Uppsala. Detailed information about the procedures to be used in measuring muscle strength was also given. At the initial examination findings of conditions such as diabetes, impaired locomotor function and disease of the nervous system gave reason to exclude 111 further subjects.

Thus, 1 039 persons from the initial sample did not participate in the study. A letter and a questionnaire (second questionnaire) identical to the first one were later sent to the 556 selected persons who did not reply to the first letter (they were also contacted by telephone). The questionnaire was completed by 248 of these people, while 308 did not send in a reply. Among the 248 respondents, 62 inactive persons (20 men and 42 women) and 13 moderately active persons (5 men and 8 women) reported illness. Information on physical activity was not supplied by 19 of those returning this questionnaire.

Fig. 1 illustrates the selection process leading up to the 280 subjects tested in this study (group A) and the 248 subjects who received and answered a second questionnaire but did not participate in the tests (group B). Table I gives information concerning anthropometrical data and physical activity of subjects in groups A and B.

Of the 280 investigated subjects, 34 men and 31 women also underwent an electrophysiological study (28) and a histochemical and metabolic study (12). Of these 65 subjects 14 men and eight women also participated in a metabolic study on pools of microdissected type I or II fibres (9).

The study were approved by the Research Ethics Committee of the Medical Faculty of the University of Uppsala.

Moderately active (n)		Inactive (n)		BSA (m²)	
A	B	A	B	A	B
16	10	11	13	1.94	1.91
16	13	10	8	1.68	1.71
16	8	10	10	1.93	1.94
17	11	13	8	1.66	1.66
12	10	11	12	1.96	1.95
20	10	10	17	1.74	1.69
12	7	9	11	1.97	1.93
10	5	7	9	1.74	1.71
11	10	10	12	1.98	1.93
15	6	2	8	1.66	1.73
15	6	6	10	1.93	1.95
15	5	6	10	1.70	1.66

METHODS

A Cybex II dynamometer (Lumex Corp., Bay Shore, N.Y.), with a modified lever arm (Aero Technical Corp., Stockholm, devised by Knutsson and Litton), and an examination table (Alfex,) were used to determine peak torque (Newtonmetre, Nm) during voluntary isokinetic and isometric contraction. The measurements followed the procedure described by Knutsson (17). Standardized measurements of muscle torque (Nm) at extension and flexion of the knee joint were made at angular velocities of 12, 90 and 150 degrees per second. Both the right and left leg were examined. The equipment was calibrated statically with weights on a lever and dynamically with weights fastened via a wire to a wheel adjusted to the centre of the axis of the Cybex II, as described by Ericsson et al. (10). Mechanical oscillations arise during the acceleration of the lever and cause curve distortion. With increasing angular velocity the mechanical artifacts due to the acceleration of the mass also increase. Therefore, 150 degrees/s was the highest velocity used. Corrections were made for the weight of the leg and for reducing the mechanical oscillations of the equipment.

The subjects performed voluntary maximum knee extensions from 90 degrees of flexion in the knee joint to 0 degrees followed by knee flexion with the lever arm attached to the right and left ankle in turn. The axis of rotation of the apparatus was aligned with the anatomical axis of rotation at the knee joint. The subjects were seated on the examination table with support for the trunk. At the 90 degree position the thighs and trunk were fixed to the table (Alfex) with wide, slightly elastic straps. Torque readings at diffe-

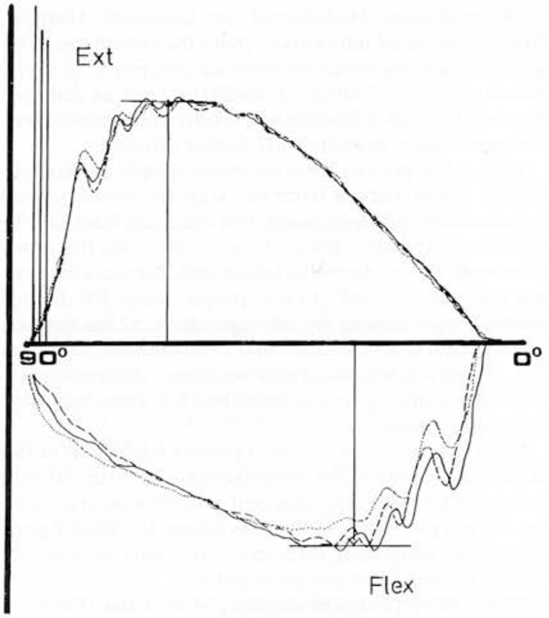

Fig. 2. Isokinetic knee extension and flexion torque and isometric knee extension torque (solid bars), Newtonmeter (Nm). Maximal isokinetic torque values are indicated. Three measurements were performed.

rent angular velocities were displayed on an XY printer (Bryant type). After having become familiar with the apparatus the subjects performed three tests (Fig. 2). They were instructed to extend the leg and then to flex the leg as quickly as possible. The experimental conditions and the practical procedures were checked before each test to ensure that the subjects were made familiar with the test and were comfortably seated. They experienced no discomfort during the measurement procedure. Maximum isometric extension torque was measured with the lever arm locked in a position of 90 degrees flexion of the knee joint. The subjects were instructed to extend the leg slowly by pressing against the measuring device. They performed three maximum contractions as in the case of the isokinetic measurements (Fig. 2).

Statistical methods

Standard statistical methods were used to calculate mean values and standard deviation (SD). For comparing height and weight between the young and old groups, two-sample *t*-tests were performed. Single and multiple regression methods were used with torque as the dependent variable and body weight, and height, body surface area, physical activity, age, sex and sides as independent variables. A two-way analysis of variance model with the factors age and sex and their interaction was used to analyse the following variables: Isokinetic and isometric torque, the difference between the right and left leg and the difference in muscle torque between the physically active and the inactive groups. If the interaction was significant for any variable, the model was reanalysed with logarithmic values to see whether the interaction was removable.

RESULTS

Anthropometric variables

Anthropometric data for the different age groups are shown in Table I. In group A as a whole the mean (and SD) body weight of the men was 78 (SD 12) kg and that of the women 64 (8) kg, and the height of the men was 177 (6) cm and that of the women 164 (5) cm. The corresponding figures for group B, who did not participate in the study, were 77 (11) and 63 (9) kg, 177 (6) and 165 (5) cm. Two sample *t*-tests revealed that in women the young group (20 years) had a significantly lower body weight ($p<0.05$) and a significantly greater height ($p<0.001$) than the old group (70 years). In men the height was significantly lower ($p<0.05$) in the old group than in the young one.

Physical activity

As a whole group A was not significantly more physically active than group B (Table I). An analysis of variance showed that in group A as a whole there were no significant differences in maximum isokinetic torque or in maximum isometric torque between moderately active and inactive men or women.

Difference between the right and left leg

In most subjects the values of maximum isokinetic and isometric torque were slightly higher in the right leg than in the left. A few subjects had a higher torque in the left leg but this was not related to left-handedness. The right leg was slightly stronger than the left one in three out of six left-handed men, and in two out of eight left-handed women. No significant difference in isokinetic flexion torque was found between the right and left leg. Regarding isokinetic extension torque at 90 and 12 degrees/s and isometric torque, there was a slight but statistically significant difference ($p<0.05$) between the right and the left leg in some age groups in both men and women. In the whole material the small difference observed between the right and the left leg was not statistically significant in an analysis of variance, either in men or in women. The results will therefore be given mainly as the values obtained from one leg, and the right leg was chosen as representative.

Influence of age on torque

There was a decrease in muscle torque with increasing age in both men and women, with the highest values in the youngest age group and the lowest ones in

Table II. *Isokinetic knee extension torque (Nm) at different angular velocities (degrees/s) in men and women of different ages (years)*

Dx = right leg, sin = left leg. Values are given as mean ($\bar{X}$) and standard deviation (SD)

			Angular velocity											
			12°/s				90°/s				150°/s			
			dx		sin		dx		sin		dx		sin	
	Age	n	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Men	20	27	289	44	269	47	231	32	217	27	180	24	179	22
	30	26	258	45	243	47	207	38	196	35	158	34	160	28
	40	23	248	29	238	42	203	27	197	31	158	24	155	26
	50	21	226	51	220	45	186	36	177	32	145	27	143	30
	60	21	223	48	212	40	179	34	169	32	142	28	136	22
	70	21	188	36	183	37	143	24	145	30	113	22	113	21
Women	20	26	183	34	172	31	143	25	137	24	110	18	106	19
	30	30	169	34	163	30	138	22	134	20	108	19	107	15
	40	30	172	28	161	26	134	20	131	20	105	15	102	14
	50	17	153	30	143	26	122	18	114	17	94	16	92	14
	60	17	145	20	126	24	113	13	99	15	84	10	79	12
	70	21	128	28	120	25	98	17	93	15	74	12	70	11

the oldest age group. This was true for both types of contractions and for all angular velocities used (Table II, III and IV). For isokinetic extension torque the most notable decrease was found from 20–30 years of age ($p<0.05$) in men, from 40–50 years of age ($p<0.05$) in women, and from 60–70 years of age ($p<0.05$) in both sexes. The isometric torque decreased significantly in both men and women between the ages of 60 and 70 ($p<0.05$). The decline in isokinetic extension and flexion torque with increased angular velocity was of about the same rate (no significant difference) in the youngest and the eldest groups.

Difference between the sexes

The isokinetic and isometric torques were significantly higher ($p<0.001$) in men than in women in each age group. In the women, the isokinetic extension torque varied between 59% (150 degrees/s) and 69% (12 degrees/s) of that in the men. In the women the flexion torque varied between 44% (150 degrees/s) and 71% (12 degrees/s) of that in the men. The isometric torque varied between 54 and 62% of that in the men. The decrease in isokinetic extension torque, expressed as the quotient of the value at 70/20 years was about 63% in men and about 69% in women. In flexion the decreases in torque were

Table III. *Isometric torque (Nm) at 90 degrees knee flexion in men and women of different ages (years)*

Dx = right leg, sin = left leg. Values are given as mean ($\bar{X}$) and standard deviation (SD)

Men						Women					
		dx		sin				dx		sin	
Age	n	$\bar{X}$	SD	$\bar{X}$	SD	Age	n	$\bar{X}$	SD	$\bar{X}$	SD
20	27	301	56	280	59	20	26	169	34	156	32
30	26	255	47	240	44	30	30	147	34	139	28
40	23	252	33	238	41	40	30	147	31	142	27
50	21	229	51	224	50	50	17	123	23	116	18
60	21	214	40	202	40	60	17	125	18	114	23
70	21	187	38	179	40	70	21	116	23	105	22

Table IV. *Isokinetic knee flexion torque measurements (Nm) at different angular velocities (degrees/s) in men and women of different ages (years)*

Dx = right leg, sin = left leg. Values are given as mean ($\bar{X}$) and standard deviation (SD)

			Angular velocity											
			12°/s				90°/s				150°/s			
	Age		dx		sin		dx		sin		dx		sin	
	(yrs)	n	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Men	20	27	155	28	144	27	122	21	113	21	96	19	91	19
	30	26	150	28	143	35	113	23	108	29	91	26	87	25
	40	23	149	22	144	24	112	18	106	21	87	16	83	15
	50	21	142	32	129	30	98	24	91	25	82	23	76	25
	60	21	130	38	133	34	95	29	86	30	78	24	75	25
	70	21	109	30	109	32	78	26	77	23	61	23	60	26
Women	20	26	100	20	95	20	68	21	66	17	49	19	46	16
	30	30	90	18	88	18	61	15	58	13	46	14	42	12
	40	30	93	20	91	18	62	14	61	13	46	14	46	13
	50	17	76	24	75	20	52	13	51	13	36	13	38	11
	60	17	77	14	74	17	53	12	47	13	38	11	35	12
	70	21	65	12	59	13	39	13	38	13	28	8	25	9

about 66 and 60% in men and women, respectively. For isometric torque the corresponding age quotient was 62% in men and 69% in women.

Flexion torque

The maximum flexion torque varied between 51 and 63% of the maximum extension torque in men, and between 36 and 59% in women, depending on the angles of velocity and the age group.

Correlation analysis

In both sexes, the isometric and isokinetic extension torque was correlated to the following variables: body height (varied between 0.44 and 0.52 for men and between 0.46 and 0.50 for women), body weight (varied between 0.30 and 0.39 for men and between 0.26 and 0.29 for women), age (varied between −0.60 and −0.63 and between −0.58 and −0.60 for men and women, respectively), body surface area (varied between 0.46 and 0.68 for men and between 0.34 and 0.62 for women). The isokinetic flexion torque was correlated to the following variables: body height (varied between 0.40 and 0.67 and between 0.22 and 0.59 for men and women, respectively), weight (varied between 0.31 and 0.46 in men and 0.11 and 0.26 in women), age (varied between −0.33 and −0.51 in men and between −0.43 and −0.54 in women).

The correlation between the isokinetic extension torque values at all measured velocities and the isometric torque varied between 0.58 and 0.86 for both men and women. In a multiple regression model with extension torque (90 degrees/s) as a function of age, height and weight, the multiple correlation coefficient was 0.80 for men and 0.73 for women. The multiple correlation coefficients with extension torque as a function of age and body surface area were 0.80 and 0.73 for men and women, respectively.

DISCUSSION

The drop-out rate in this investigation was considerable and the sample studied cannot be considered as truly representative of Uppsala and its vicinity. However, their characteristics (height and weight) were in agreement with observations made at health surveys carried out in Uppsala in 1961/62 and in 1969/70 (11) (Fig. 3). Among the 60-year-old men there were three men with pronounced overweight. This affected the mean weight as seen in Fig. 3. The anthropometric comparison between the individuals who participated in this study (group A) and the non-responders (group B) showed close agreement in terms of height, weight, and body surface area.

Twenty-eight per cent of the respondents who underwent the medical examination were excluded from the study. The aim of this examination was to select a group of clinically healthy test subjects, "clinically healthy" meaning free from illness affect-

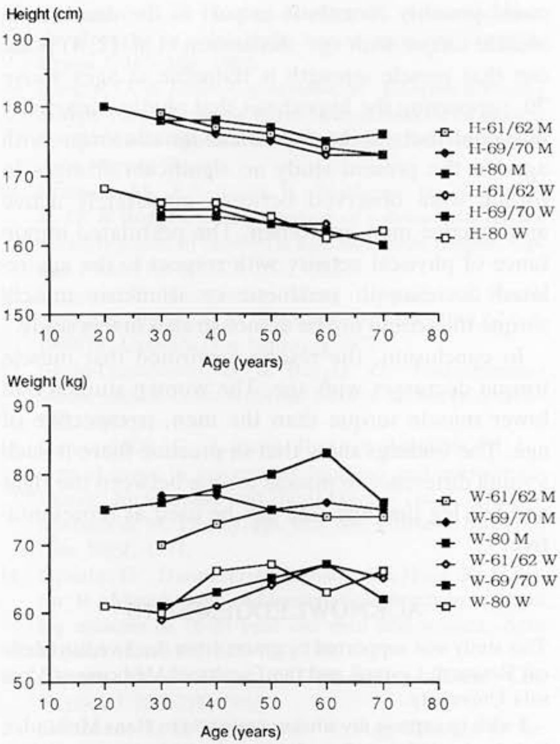

Fig. 3. Comparison of height (cm) and weight (kg) between the subjects in this study and the health surveys carried out in Uppsala in 1961/1962 and in 1969/1970. Men = M, Women = W. Mean values are given.

ing their general state of health or muscles in the lower extremities.

From studies of persons of different body size, age and sex, Asmussen et al. (6) and Lambert (18) concluded that the correlation between muscle strength in symmetrical muscle groups (right and left) was quite high (r=0.8). In the present study both legs were tested and no significant differences were observed between the left and right leg in the whole material. The physiological decline in muscle torque in older age groups may be due to many factors. Reduced fibre areas in old age may partly explain the reduction in muscle mass and muscle torque that occurs in the ageing process (14, 19, 31). Of the 280 examined subjects (group A), 34 men and 31 women aged 20–70 years underwent a study of histochemical, glycolytic and oxidative enzymatic changes with age (12). It was found that in both sexes the area of type II fibres decreased with age (II A especially in women and II B only in women).

In a multiple regression analysis, when the influence of type II fibre area on torque was eliminated, age still had a significant inverse correlation with torque (19). It was suggested that other factors than the area of type II fibres contributed to the decrease in muscle torque with age. In other studies more fat and connective tissue elements, as well as fibre atrophy, which was more pronounced in type II fibres, was observed in older subjects (26, 30). Recent findings indicate that there is also a loss in the total number of muscle fibres between the ages of 30 and 70 years (15, 20, 21). The relative distribution of fibre types was found to be unaltered between 20 and 70 years in the study of Essén-Gustavsson & Borges (12). Another important physiological mechanism that may contribute to a decline in muscle torque with age is the occurrence of changes in the neuromuscular system with a progressive decrease in the trophic function of the nerve cell in old age (16). The subjects of the study of Essén-Gustavsson & Borges (12) also participated in an electrophysiological study in which an increase in fibre density and in the macro motor unit potential (MUP) amplitude (macroEMG) with age was found (28). The increasing size of the motor units with increasing age is probably a sign of compensatory reinnervation of the motor units due to reinnervation by collateral sprouting.

Earlier studies regarding enzyme activities in whole muscle pieces show little or no change in the enzyme activities with age (5, 12, 33). In a subsample in the present study the myokinase activity was determined in microdissected type I and II fibres in 14 men and eight women aged 20–70 years. The myokinase activity decreased markedly with age in both fibre types. Furthermore, in men, myokinase activity in type II fibres was significantly correlated to muscle torque (9). This suggests that the decline in myokinase activity might be a factor of importance for the decline in muscle torque with age.

Thus, the reduction in muscle torque with age found in the present study may partly be explained by a reduction in fibre areas, but the decrease of myokinase activity in type II fibres and the loss of motor units due to degenerative changes in motor neuron or axon must also be taken into consideration.

Isometric and isokinetic torque in men does not differ very much between the ages of 30 and 60 years. It thus seems that after the greater decrease between 20 and 30 years, the torque remains at approximately the same level between 30 and 60, after which there is a decline with age in the oldest group.

This finding is in contrast to reports from previous studies (19) in which an increase in muscle torque was found between the ages of 20 and 30 years. No explanation can be given at present for these conflicting results.

The results of the present study are in accordance with those of Åstrand & Rodahl (32), who measured the maximum oxygen uptake during exercise in 350 healthy, moderately well trained males and females ranging in age from four to 65 years. The aerobic capacity increased up to 20 years of age and then decreased gradually with age in both sexes. Muscle torque and aerobic capacity thus seem to change according to the same pattern with age. In a review Grimby & Saltin (15) commented that the decline in maximal oxygen uptake with age cannot account for the factors that influence the decline in muscle strength in the ageing process. The decline in maximal oxygen uptake with age is due to a reduction in maximal heart rate, impaired myocardial contractility and increased stiffness of the larger vessels in the arterial tree (13).

The maximal isometric torque and the maximal isokinetic extension and flexion torque were on an average lower in women than in men. In the case of the subjects of the present study who underwent a histochemical (12) and an electrophysiological study (28), the area of each fibre type was larger in men than in women regardless of age, which may have contributed to the sex differences. The difference in body dimensions must be considered when evaluating difference in torque between the sexes. In this study stronger muscle torque was correlated to greater height, weight and BSA, and men have larger body dimensions than women. The percentage decrease in mean isokinetic and isometric torque between the ages of 70 and 20 years did not differ greatly between the sexes.

The present results are in accordance with other findings of higher isometric than isokinetic torque and decreasing torque with incresing isokinetic velocity for the knee extensor muscles (24, 27, 29). Thorstensson et al. (29) found a correlation between maximum torque produced at the highest angular velocity and the percentage as well as relative area of type II fibres. Their finding indicated that the type II fibres may produce relatively greater force at higher velocities. In this present study it is possible that the type II fibre atrophy has influenced the decrease in torque with increased angular velocity.

A reduction in physical activity in elderly people could possibly contribute in part to the decrease in muscle torque with age. Aniansson et al. (2, 4) point out that muscle strength is trainable at ages above 70, supporting the hypothesis that physical inactivity may contribute to the decrease in muscle torque with age. In the present study no significant changes in torque were observed between moderately active and inactive men or women. The postulated importance of physical activity with respect to the age-related decrease in isokinetic or isometric muscle torque thus could not be demonstrated in this study.

In conclusion, the results confirmed that muscle torque decreases with age. The women studied had lower muscle torque than the men, irrespective of age. The findings show that in practice there is such a small difference in muscle torque between the right and left leg that any side can be used as representative.

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Address for offprints:
Octavia Borges, M.D.
Department of Rehabilitation Medicine
Uppsala University
Akademiska sjukhuset
S-751 85 Uppsala
Sweden