Scand J Rehab Med 29: 213–221, 1997

# REDUCED MUSCLE FUNCTION IN PATIENTS WITH OSTEOARTHRITIS

Nadine M. Fisher EdD,[1] and David R. Pendergast EdD[2]

*From the Departments of [1]Rehabilitation Medicine, and [1,2]Physiology, State University of New York at Buffalo, Buffalo, NY, USA*

**ABSTRACT. The purpose of this study was to determine whether subjects with knee osteoarthritis (OA) had reduced muscle strength at various muscle lengths, endurance, contraction velocity and functional capacity, compared with control subjects and whether the decrease was related to functional capacity. Forty-five men and 45 women with knee OA were compared with a control group (41 males, 63 females) of similar age for functional capacity, maximal isometric strength (*in vivo* length-tension relationship) and endurance (*in vivo* force-time relationship) of knee flexion and extension and maximal angular velocity (*in vivo* force-velocity relationship) of knee extension. The OA subjects had increased difficulty (2.03 ± 0.53) and pain (1.65 ± 0.29) for activities of daily living (ADLs) and significantly lower strength for extension (72%) and flexion (56%), endurance for the quadriceps (203%) and hamstrings (214%) and velocity (128%). The reductions were greater at longer muscle lengths. These data demonstrate that patients with knee OA have reduced muscle function and functional capacity compared to controls.**

*Key words:* angular velocity, functional capacity, isometric, muscle endurance, muscle strength, osteoarthritis.

## INTRODUCTION

Osteoarthritis (OA) is a prevalent disease in middle-aged and elderly individuals (23) which can lead to disability. The progression of OA results in inflammation, joint pain, deformity, decreased range of motion, etc., which collectively may lead to functional limitations (3, 12). These symptoms cause increased difficulty, pain and dependency (16) in the ability to perform activities of daily living (ADLs). These limitations may cause a loss of independence much earlier in patients with OA than in healthy, elderly patients without OA.

Clinically, the symptoms of OA appear at the age when there are significant decreases in muscle function (muscle strength, endurance and angular velocity) (10). The incidence of OA over the age of 55 is greater in women than in men (5, 18). Women also have significantly lower absolute values for muscle function than men (10). It has previously been reported that the inflammation and pain associated with OA may lead to reduced activity and neuromuscular inhibition (20). The last two factors may, in concert, lead to significant reductions in muscle function.

While some attention has been given to the decline in quadriceps muscle strength with OA, it has been measured at only one position (joint angle and muscle length). This is not the only muscle length or joint angle that is used functionally when standing, climbing stairs or rising from a chair, which are the activities that are problematic for patients with OA. Furthermore, the hamstring muscle group, in concert with the quadriceps, stabilizes the knee, thus distributing the weight across the cartilage of the knee and protecting the joint. The ability of a muscle to contract rapidly (velocity) and to continue to contract over time (endurance) has not been measured in elderly subjects or patients with OA. If the quadriceps and/or hamstring muscle groups have reduced function, particularly at the longer muscle lengths in patients with OA the knee joint may be subject to increased deterioration and further injury during ADLs. Functional capacity is not determined by one contraction (strength), but by the ability to sustain or repeat a series of contractions, termed "muscle endurance" or "fatigue ability". The ability to contract muscle rapidly against fixed resistances is important functionally as this is how activities are performed and also how damage or injuries to joints are prevented. Little evidence is currently available on muscular endurance (force-time relationship), velocity of muscle contraction (force-velocity relationship) or hamstring function in OA patients. We have previously shown that these parameters are altered in elderly subjects, therefore it is reasonable to assume that, like strength at short muscle lengths, the deterioration of these parameters will be exacerbated by OA. Likewise, if there are deficits, it is reasonable to postulate that a rehabilitation program would improve these parameters and improve function, reduce deterioration and perhaps prevent injury during ADLs as has been shown in elderly subjects (9) and patients with OA (6–8, 11).

The purpose of this study was to determine whether subjects with OA of the knees had significantly reduced muscle strength, particularly at longer muscle lengths (length-tension relationship), endurance (force-time relationship) and muscle contraction velocity when opposed by resistances (force-velocity relationship) in both quadriceps and hamstring muscle groups. In addition, an examination of the relationship between the measured muscle functions and functional capacity in patients with OA was compared with that for control subjects.

## MATERIALS AND METHODS

Forty-five men and 45 women (65.0 ± 10.2 yrs) were randomly selected from 437 volunteers, previously diagnosed with OA, for participation in the study, using simple random sampling procedures and a table of random numbers (14). All OA subjects volunteered as a result of a newspaper advertisement. They were required to bring a referral with confirming diagnosis from their primary care physician, rheumatologist or orthopedic surgeon at the time of their first appointment. The subjects were given a medical history, physical and weight-bearing AP knee X-rays to confirm the diagnosis of OA and to clear them for inclusion in the study. The criterion used for admission was the presence of radiographically documented Grade 2 or greater OA (17) of the knees. The X-rays were evaluated by a rheumatologist and a radiologist using the standards of Kellgren & Lawrence (17). Using this scale, the degree of severity of knee OA is rated from 1 (none) to 4 (severe) based on the radiographic evidence. The presence of osteophytes on the tibial spines, the degree of joint narrowing and the presence of pseudocystic areas with sclerotic walls were used as the criteria. The scale has been found to be valid and reliable for the knee when two raters are used, as was the case in this study (17). Nine volunteers (4 males and 5 females) failed to meet these criteria and were subsequently replaced with volunteers, randomly selected from the volunteer sample by the same method, who did meet the criteria. A control group (41 males and 63 females) (68.2 ± 5.0 yrs) volunteered from the populations of two senior citizen centers. The controls were given a history and a physical examination to ensure that they did not have symptomatic OA or any medical or functional limitations. We realize that some of the controls may have had asymptomatic OA. Owing to cost and radiation exposure, no X-rays were taken in the control group. No attempt was made to match the OA and control subjects. All subjects had to be over 60 years of age and living independently. All subjects gave informed consent prior to participation. The subjects then participated in a series of measurements to assess their functional capacity and muscle function.

### *Functional capacity assessment*

The functional capacity measures conducted were the Jette Functional Status Index (JFSI) and 50 foot walking time. Walking time was measured indoors, walking 50 ft. forward at maximal speed. The JFSI has been shown to be reliable and valid for patients with osteoarthritis, including those with affected knees (7, 16). It measures both upper and lower extremity function, assessing the degrees of dependence, difficulty and pain encountered when performing various ADLs. Although there is some controversy regarding subjective testing, some investigators suggest that this type of testing is valid as a measurement of functional capacity and pain (20, 21).

### *Muscle function assessment*

Maximal isometric strength at various muscle lengths, endurance and angular velocity were measured to generate the physiologic *in vivo* length-tension (strength), *in vivo* force-time (endurance) and *in vivo* force-velocity (angular velocity) relationships. The muscle function measurements were conducted on three separate days, with at least one rest day in-between, so as to minimize the effects of fatigue. Prior to actual data collection on the first day, subjects familiarized themselves with the equipment and practiced the measurements. For the strength measurements, the subjects were given two trials at one position, followed by a 3-minute rest to recover their high-energy phosphates. This was then repeated for all positions. One endurance measurement for the quadriceps and hamstrings for each leg was determined at the end of each day of testing. Angular velocity measures started at zero resistance and progressed to the highest resistance (4.5 kg) for one position. Three minutes rest was given between resistances. The angular velocity measurements at the various positions were spread equally over the three testing days. The subjects were encouraged not to hold their breath, especially during the endurance contractions, thus avoiding a Valsalva maneuver which would increase heart rate and blood pressure. All muscle function measurements were performed on a specially designed exercise bench, which has been previously described (8, 10, 11).

Maximal isometric quadriceps force was measured, with a strain gauge, at three knee flexion positions and five hip flexion/extension positions, on the specially designed bench (Fig. 1). The different knee flexion positions (43°, 90° and 104°) were used because of the effects on strength and motor unit recruitment produced when varying knee position (15, 19, 22). The different hip flexion (120°, 90°, 60° and 30°) and hip extension (0°) positions were used to stretch the rectus femoris. The rectus femoris muscle length, from the anterior inferior iliac spine to the tibial tuberosity, was measured at all hip flexion/extension

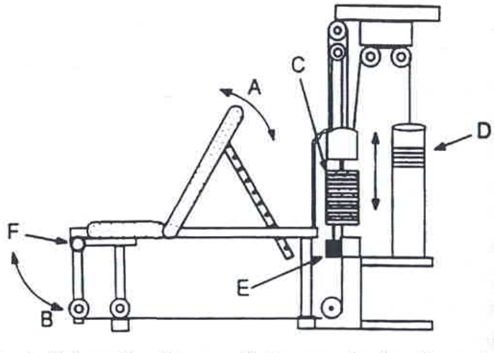

*Fig. 1.* Schematic diagram of the exercise bench used for quantitative testing of muscle function. A = Variable hip angle; B = Variable knee angle; C = Weight stack; D = Counter weighting system; E = Force transducer; F = Potentiometer.

and knee flexion position combinations. Each maximal isometric contraction was performed for 2 to 3 seconds. Two trials with each leg, in each of the 15 positions, were performed with the highest value from the weakest leg used for the analyses. The subject alternated legs for each contraction in order to minimize fatigue. Torque was calculated by multiplying the force by the lever arm (distance between the lateral joint line and the point of force application) for each subject. Measurements of maximal isometric hamstring strength were made at one hip extension (0°) and three knee flexion (14°, 29° and 43°) positions by the same procedure. The knee and hip angles were chosen to reflect the functional length of the muscle as well as subject acceptability.

Quadriceps endurance was measured at each knee flexion position (43°, 90° and 104°), but only at one hip flexion position (30° or 60°) for each leg. This approach was adopted in order to minimize fatigue that would occur if more muscle lengths were evaluated. The force sustained during an endurance contraction was also measured using a strain gauge. The subject maintained a maximal isometric contraction (force) for as long as possible or a maximum of 90 seconds. Endurance was calculated as the area under the fatigue curve or the tension-time index. Measurements of maximal isometric hamstring endurance were made at one hip extension (0°) and three knee flexion (14°, 29° and 43°) positions by the same procedure.

Angular velocity is a measurement that is frequently ignored, but that is of critical importance when discussing overall muscle function, especially of patients with any musculoskeletal or neuromuscular diseases. The velocity of muscle contraction is important functionally because of its role in balance (corrective compensations) and the prevention of falls. Maximal angular velocity was measured using a potentiometer attached to the axis of rotation of the knee extension arm. Using this type of equipment, a measure of angular velocity can be made for a given resistance (force-velocity relationship), as opposed to using a predetermined velocity to measure torque production (isokinetic device). The muscle function measurements used in this protocol mimic the use of muscles during ADLs and are safe for patients with disease. Maximal angular velocity measurements were made by having the subjects move the knee extension arm as rapidly as possible through their range of motion. This was done with five resistances (0, 1, 2, 3 and 4.5 kg), thereby generating an *in vivo* force-velocity curve. Angular velocity was measured at four hip positions (90°, 60° and 30° (flexion) and 0° (extension)). Two trials were performed with each resistance and hip position for each leg (alternating repetitions). The resistances were kept at these low levels due to the potential pain and discomfort that could result in OA subjects doing a maneuver with heavier resistances. The equipment for the muscle function measurements has been used in several studies (6–11) where repeated measures of the same parameter were made on different days on the same subject. These data demonstrate that the measures of isometric strength at all muscle lengths, muscle endurance and angular velocity are reliable, with correlation coefficients of 0.93, 0.86 and 0.79, respectively (7, 10).

Maximal handgrip strength and endurance were measured for each hand with a standard Stoelting handgrip dynamometer. The handgrip data were collected to show the differences between the function of the supporting musculature of an unaffected (hand/wrist) vs an affected (knee) joint.

### *Data analysis*

The primary purpose of this study was to compare the functional capacity and muscle function of the OA group with that of the control group. As secondary analyses, the effects of changing joint position (muscle length) on muscle function and comparisons between men and women were completed. Each leg was measured and compared individually. The data for the weakest leg are presented as this leg typically had a higher degree of OA in the knee joint. Furthermore, the weak leg is the limiting factor in performing lower extremity functional activities. The values presented are means ± standard deviations. The observers could not be blinded as to whether the subjects were controls or had OA as the test population had to be evaluated in two different locations.

An analysis of variance for repeated measures was used separately on the OA and control groups to determine the effects of changing muscle length on quadriceps and hamstring strength and endurance, and of increasing resistance on angular velocity.

The OA subjects were divided into two groups on the basis of disease severity—those with less than Grade 3 OA and those with Grade 3 or greater OA. ANOVAs were performed to determine the effects of OA severity on muscle function and functional capacity.

Analyses were performed on the men vs the women for both groups as typically muscle mass is greater for men than for women. The data for the men and women in the OA group and control group were compared using a two-way ANOVA for quadriceps and hamstring strength and endurance as a function of changing hip and/or knee position, angular velocity as a function of increasing resistance and functional capacity as a function of dependence, difficulty and pain. Walking time and the JFSI between the OA and control groups and men and women were compared by means of Mann-Whitney two sample tests.

Correlation coefficients (Pearson Product-Moment) were determined in order to examine the inter-relationships between the various measures of functional capacity and muscle function.

Based on the large number of randomly selected subjects, the similarity in numbers in the OA and control groups and between men and women in each group, the data for the men and women in each group were combined and analyzed by a two-factor repeated measures ANOVA comparing OA to control for: (1) quadriceps strength as a function of all hip and knee positions; (2) quadriceps endurance as a function of all hip and knee positions; (3) hamstring strength as a function of knee position; (4) hamstring endurance as a function of knee position and (5) angular velocity for all resistances and hip positions. An alpha level of $p < 0.01$ was used for all statistical comparisons to minimize loss of power due to the multiple comparisons made.

## RESULTS

The physical characteristics of the subjects are presented in Table I. The age and height of the OA group were not significantly different from the control group. The OA group was significantly heavier than the control group ($p < 0.01$).

Since there were no significant differences between the severity of OA and the muscle function and functional capacity results ($p < 0.01$), the two OA groups were combined. The control group had no symptoms of OA.

Statistically significant ($p < 0.01$) gender differences were observed for the control group for muscle function

Table I. *Physical characteristics of subjects (mean ± SD)*

| | Osteoarthritis | Control | Significance ($p < 0.01$) |
|---|---|---|---|
| *n* | 90 | 104 | |
| Age (years) | 65 ± 10.2 | 68.2 ± 5.0 | NS |
| Height (cm) | 168.6 ± 8.6 | 166.2 ± 6.1 | NS |
| Weight (kg) | 85.0 ± 16.7 | 70.3 ± 8.4 | * |

NS: not significant; *: significantly different from control ($p < 0.01$).

and walking speed. There were significant differences between the OA men and women for strength and endurance. The magnitude of difference between the men and women was similar for both the control and OA groups.

*Functional capacity*

The data for the measures of functional capacity can be found in Fig. 2. The data for the JFSI are presented in the upper plate. The OA subjects were not significantly more dependent than the control subjects; however, they had significantly more difficulty and pain. There were no significant differences in the JFSI between the men and women in either group. Walking time (see Fig. 2, lower plate) was significantly higher in the OA group than in the control group. There were no significant differences in walking time between men and women in the OA group (10.3 ± 2.5 seconds vs 11.1 ± 3.1 seconds, respectively).

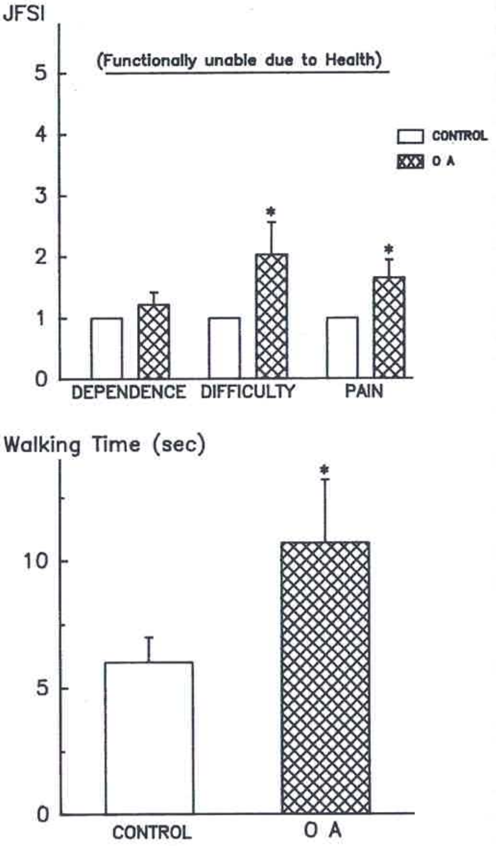

*Fig. 2.* Mean ± SD for the Jette Functional Status Index (JFSI) (upper plate) and 50 foot walking time (seconds) (lower plate) plotted for the control (open bars) and osteoarthritis (OA, cross-hatched bars) groups. The SD for the control group was 0 for the JFSI. The * indicates a significant difference ($p < 0.01$) from the control group.

*Muscle characteristics*

The maximal rectus femoris muscle length of the OA subjects (measured at 0° hip extension) was significantly shorter than that of the controls (54.8 ± 1.8 cm vs 57.2 ± 3.4 cm, respectively). The maximal rectus femoris muscle length of the men was significantly greater than that of the women in the OA group (57.2 ± 2.4 cm vs 52.4 ± 2 cm, respectively).

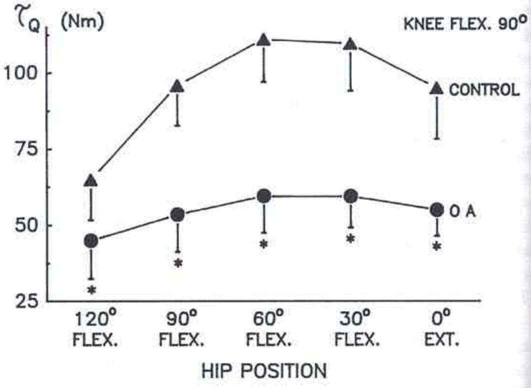

*Fig. 3.* Mean ± SD of maximal isometric knee extension torque (quadriceps) (Nm) for the control and osteoarthritis (OA) groups plotted as a function of hip flexion/extension position (degrees) (increasing muscle length). The knee was fixed at 90° of flexion. The closed triangles indicate the controls and the closed circles indicate the osteoarthritis patients. The * indicates a significant difference ($p < 0.01$) from the control group.

*Muscle function*

*Strength.* Maximal isometric torques for knee extension strength at five hip positions (increasing rectus femoris muscle length from 120° of hip flexion to 0° of hip extension) are shown in Fig. 3. There were no significant increases in torque as the hip position was decreased (from 120° to 0°) (i.e. muscle lengthened) in the OA

Table II. *Comparison of muscle function in osteoarthritic men and women (mean ± SD)*

| | Men | Women | Significance ($p < 0.01$) |
|---|---|---|---|
| *Strength* | | | |
| Quadriceps (Nm) (knee 90°, hip 30°) | 81.2 ± 25.6 | 37.6 ± 10.3 | * |
| Hamstring (Nm) (knee 14°) | 31.3 ± 9.6 | 15.9 ± 5.8 | * |
| Handgrip (N) | 345.5 ± 93.0 | 201.5 ± 54.1 | * |
| *Endurance* | | | |
| Quadriceps (Nm · sec) (knee 90°, hip 30°) | 3,295.4 ± 2,063.2 | 2,066.8 ± 1,124.8 | * |
| Hamstring (Nm · sec) (knee 14°) | 1,121.0 ± 681.6 | 584.5 ± 355.7 | * |
| Handgrip (N · sec) | 16,486.4 ± 8,089.4 | 8,600.8 ± 3,700.4 | * |
| Angular velocity (deg · sec$^{-1}$) (hip 30°, 0 kg) | 163.9 ± 30.2 | 152.1 ± 34.3 | NS |

NS: not significant; *: significantly different from the osteoarthritic men ($p < 0.01$).

group. In the control group, the torques at hip flexion positions of 60° and 30° were significantly higher than those at 120° and 90° (hip flexion) and 0° (hip extension). The torque values for the control group were 63%, 73%, 83%, 80% and 63% greater than those for the OA group at hip positions of 120°, 90°, 60°, 30° and 0°, respectively. The control values were, on average, 72% higher than the OA values at all muscle lengths. The maximal isometric quadriceps strength of the OA men was significantly greater than that of the OA women (Table II).

Maximal isometric torques for hamstring flexion strength at three knee positions (decreasing muscle lengths from 14° to 43° of flexion) are presented in Fig. 4. The values for the OA group were not affected by changing knee position. The maximal isometric hamstring strength of the OA men was significantly greater than that of the OA women (Table II).

Maximal isometric handgrip strength was slightly reduced in the OA subjects when compared to controls (273.5 ± 54.1 N vs 291.8 ± 60.8 N, respectively) and was significantly greater for the OA men than for the OA women (Table II).

*Endurance.* The average value for quadriceps endurance with the hip flexed at 30° and the knee flexed at 90° was greater than those obtained at any other knee flexion position in both groups. The quadriceps endurance for the OA group (2,681.1 ± 1,124.8 Nm·sec) was significantly lower than the value for the control group (8,125.0 ± 4,063.0 Nm·sec). Maximal hamstring endurance, measured at the longest muscle length (knee flexed at 14°), was 852.8 ± 355.7 Nm·sec in the OA group and 2,679.0 ± 1,498.0 Nm·sec in the control group. Maximal handgrip endurance was 12,544.1 ± 3,700.4 N·sec in the OA group and 16,752.3 ± 5,673.5 N·sec in the control group. The values for the same variables were significantly greater for the OA men than for the OA women (Table II).

*Angular velocity.* The data for maximal angular velocity are presented in Fig. 5. For any resistance, the OA group had significantly slower angular velocities than the control group ($p < 0.01$). In the OA group, the angular velocity did not decrease significantly as a function

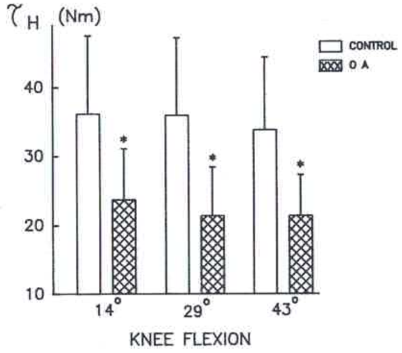

*Fig. 4.* Mean ± SD of maximal isometric knee flexion torque (hamstrings) (Nm) for the control (open bars) and osteoarthritis (OA, cross-hatched bars) groups plotted as a function of knee flexion position (degrees). The hip was fixed at 0° of extension (prone). The * indicates a significant difference ($p < 0.01$) from the control group.

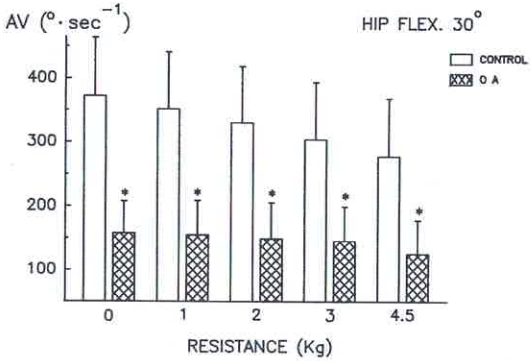

*Fig.* 5. Mean ± SD of maximal angular velocity (degrees·second$^{-1}$) for the control (open bars) and osteoarthritis (OA, cross-hatched bars) groups plotted as a function of increasing resistance (kg). The hip was fixed at 30° of flexion. The * indicates a significant difference ($p < 0.01$) from the control group.

of increased resistance ($p < 0.01$). In the control group, the angular velocity decreased significantly from 372.3 ± 91.3 degrees·second$^{-1}$ to 277.6 ± 90.6 degrees·second$^{-1}$ as the resistance was increased from 0 kg to 4.5 kg, respectively. There were no significant differences in the maximum angular velocity (hip flexed at 30°) between the men and women in the OA group (Table II).

The data for isometric strength presented in this study for control subjects and for those with knee OA are in agreement with comparable measurements previously reported for elderly subjects (9, 10, 15, 19, 24, 26) and OA patients (20, 21, 26). No comparable data are available for muscle endurance and contraction speed for these groups. Based on these similarities, we propose that our measurements of isometric strength at other joint angles, muscle endurance and contraction speed are representative of the elderly and OA subjects.

*Inter-relationships.* The inter-relationships between variables were examined on the data for the OA group only. The correlation coefficients ($r$) between the indices of functional capacity revealed that there were significant relationships ($p < 0.01$) between all combinations of pairings of dependence, difficulty and pain on the JFSI and walking time. The strongest relationship was that between difficulty and pain on the JFSI ($r = 0.84$) and the weakest was that between walking time and dependence on the JFSI ($r = 0.41$) (see Table III).

The correlation analyses for quadriceps strength at the three different knee angles were statistically significant and showed high correlations. For example, for knee angles of 104°, 90° and 43°, the correlation coefficients were 0.83 (104° vs 90°), 0.81 (104° vs 43°) and 0.78 (90° vs 43°), respectively, at a hip angle of 30°. The correlations between hip angles were also significant. For example, at a knee angle of 90°, the correlation coefficients were 0.85 (120° vs 90°), 0.91 (90° vs 60°), 0.93 (60° vs 30°) and 0.88 (30° vs 0°). The correlation coefficient between 120° and 0° ($r = 0.76$) was also highly significant. The correlations between the knee

Table III. *Pearson correlation coefficients (r) for functional capacity and muscle function variables*

| | Functional capacity | | | | Muscle function | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WT | Dep. | Diff. | Pain | Str quads. | Str hams. | End quads. | End hams. | AV |
| Walking time | 1.00 | 0.41* | 0.50* | 0.45* | −0.44* | −0.36* | −0.40* | −0.34* | −0.49* |
| Jette Functional Status Index | | | | | | | | | |
| Dependence | | 1.00 | 0.56* | 0.55* | −0.15 | −0.12 | −0.26 | −0.22 | −0.07 |
| Difficulty | | | 1.00 | 0.84* | −0.19 | −0.14 | −0.23 | −0.26 | −0.20 |
| Pain | | | | 1.00 | −0.17 | −0.16 | −0.26 | −0.28 | −0.11 |
| Strength | | | | | | | | | |
| Quads. (hip 30°/knee 90°) | | | | | 1.00 | 0.66* | 0.45* | 0.36* | 0.64* |
| Hams. (knee 14°) | | | | | | 1.00 | 0.44* | 0.72* | 0.41* |
| Endurance | | | | | | | | | |
| Quads. (hip 30°/knee 90°) | | | | | | | 1.00 | 0.60* | 0.30 |
| Hams. (knee 14°) | | | | | | | | 1.00 | 0.19 |
| Velocity (hip 0°/4.5 kg) | | | | | | | | | 1.00 |

*: significantly correlated variables, $p < 0.01$. WT: walking time, Dep.: dependence, Diff.: difficulty; Str.: strength; End.: endurance; AV: angular velocity; Quads.: quadriceps; Hams.: hamstrings.

angles for hamstring strength were 0.76 for 14° to 29°, 0.66 for 14° to 43° and 0.75 for 29° to 43°. They were significantly correlated. The correlations for endurance at the different knee and hip angles were similar to the results observed for strength, with coefficients ranging from 0.60 to 0.75. Correlations among the time intervals of the endurance contractions (15 to 90 seconds) were significant and ranged from 0.87 to 0.97 for knee flexion and extension. The correlation coefficients for angular velocity between hip angles and resistances were all significantly related with the coefficients ranging from 0.65 to 0.91.

The inter-relationships between the different variables examined in the OA subjects are presented in Table III. As indicated, the JFSI variables (dependence, difficulty and pain) were not significantly correlated to muscular strength, endurance or contraction velocity. Walking time was weakly related to muscle function. The measures of strength between the quadriceps and hamstrings were well correlated to each other, as were measures of endurance. However, strength, especially for the quadriceps, was only weakly to moderately related to endurance. Angular velocity was significantly correlated with strength, but not with endurance in this OA population.

## DISCUSSION

The present study clearly indicates that the OA subjects had reductions in functional capacity and muscle function. The increases in walking time (78%) and difficulty (103%) and pain (65%) of performing various activities of daily living (JFSI) were comparable to the data previously reported by others for OA patients (6, 7, 11, 16). The degree of limitation of these patients was not sufficient to increase their level of dependency. Other investigators have reported that OA patients eventually become more dependent (13, 27) as their disease progresses; however, not to the degree observed in rheumatoid arthritis patients (2, 26). The low level of dependency in OA patients is most likely one of the reasons they are not routinely referred to physical or occupational therapy. In many cases, they are advised to "learn to live" within the limitations of their symptoms. For example, of the 437 patients who volunteered for this study, less than 2% had previously received physical or occupational therapy; however, all of them suffered from increasing difficulty and pain.

The isometric muscle strength data presented in this study for the control subjects and OA subjects are in agreement with comparable measurements previously reported for elderly subjects (9, 10, 15, 19, 24, 26) and patients with OA (20, 21, 26). Based on these similarities, we propose that our measurements of isometric strength at other joint angles, muscle endurance and contraction speed are representative of the elderly and patients with OA of the knee. The data for the age group investigated in this study (55–75 years) are about 50% less than similar values for younger subjects (20–30 years) (10). The hamstring strength data for the control subjects from the present study would appear to be about 20% less than reported in another study (24). This could be accounted for by sampling variability. We are unaware of comparable data for control subjects for quadriceps and hamstring endurance and/or angular velocity.

The body weight of the OA subjects was greater than that of the control subjects. In general, most of the increase in body weight in the OA subjects is due to an increase in the percentage of fat, as a result of reduced physical activity (1, 4). It could also be argued that there is muscle atrophy and motor unit inhibition as a result of lower activity levels and pain. Since the muscle force is proportional to the muscle cross-sectional area, correcting for overall body weight in these measurements of muscle function may be misleading as it would exaggerate the differences between OA and control subjects. It was outside the scope of this study to quantitatively measure cross-sectional area of muscle. If the data were corrected for body weight, then the results for the OA group would appear even more significant.

It is important to measure these muscle physiology variables at the different knee/hip positions, i.e. muscle length. Previous studies have concentrated on quadriceps strength as measured in the sitting position, where the muscle is in a shortened position and the force is low. However, patients with OA have difficulty with activities, such as rising from a chair and climbing stairs, that require a higher force to be generated at longer muscle lengths; this has not been previously evaluated. Furthermore, the alignment about the knee and the distribution of forces on the cartilage are dependent upon the isometric contraction of both the hamstring and quadriceps muscle groups. Many ADLs require dynamic movement, with rapid contraction (velocity) of the muscle. The inability to contract a muscle rapidly against gravitational or external resistances has been implicated in falls and other joint injuries. Based on the importance of these variables to patients with OA, we attempted to quantify the deficits in these parameters.

The values for all muscle function parameters (strength, endurance and angular velocity) in the OA group were significantly lower than similar values in the control group. The magnitude of the reductions was 72% and 56% for strength of the quadriceps and hamstrings, 203% and 214% for endurance of the quadriceps and hamstrings and 128% for angular velocity. The reductions in endurance were greater than those observed for hamstring strength and angular velocity. There was no difference in handgrip strength between the OA and control groups (7%), although the handgrip endurance was somewhat lower in the OA group (34%). These results indicate that there is decreased function of the musculature supporting the affected knee; however, there was normal function of the musculature supporting the unaffected hand and wrist. This would mean that the changes in function as measured by the JFSI would reflect changes in only the lower limb.

The observed values of muscle function for the OA subjects in this study are only 10% higher than those values that have been suggested to be necessary to perform ADLs (10, 25). The greatest difficulty was reported for climbing stairs and rising from a chair, i.e. activities that require a high force and contraction speed.

The reductions in quadriceps strength were greater than those for hamstring strength. In the OA group, the torque did not increase with increasing muscle length as was seen for the control group. The strength reductions were greater at the longer, but not the longest, muscle lengths. These are functionally more important in rising from a chair or climbing stairs. The difference at the longest muscle length was not greater than at the shortest muscle length, as the absolute torque of the control subjects decreased at the longest length. These findings are in agreement with what has previously been shown for healthy, aging subjects. Specifically, the reductions in function were more pronounced at the longer muscle lengths (10). In fact, the maximal muscle length that the OA subjects could achieve was significantly less (less hip extension) than that for the controls.

We are aware that some of the control subjects may have had asymptomatic OA since we did not X-ray them. If they did have OA, the differences between the two groups would not have been as significantly different from each other. Although we did not match the control and OA subjects, our large groups of OA and control subjects were of similar age. Furthermore, our data are comparable with other studies that performed the same measurements (9, 10, 15, 19–21, 24, 26) on fewer subjects. Therefore, our samples are representative of OA patients and control subjects.

### *Clinical application*

Most of the subjects in this study had knee pain when standing, walking or climbing stairs. Recent evidence has shown that improvements in muscle function provide better support to the joint, thereby reducing pain during activity (6, 7, 11). Although the correlation between muscle function and functional capacity in the present study was not strong, previous studies in the elderly (9) and patients with OA (6–8, 11) have shown that increases in muscle performance were associated with increases in functional capacity.

The reductions in endurance demonstrated in this study would result in a declining stability of the knee over the length of a day (i.e. when performing ADLs). This may lead to an exacerbation of the OA symptoms and perhaps hasten the progression of the disease. Likewise, the OA patient is more susceptible to injury as the ability to correct for body movement is reduced due to the decrease in the muscle contraction velocity, resulting in patient stumbles, falls, etc.

Therefore, any type of rehabilitation program should focus on alleviating the patients' symptoms through improving muscle function. Since patient symptoms, especially pain, may eventually lead to total joint arthroplasty, in many cases, improvements in muscle function may reduce pain and prolong the time until surgery. A specific exercise intervention has been shown to improve muscle function and functional capacity in patients with OA of the knees (7, 8, 11).

In conclusion, there is a decrease in the muscle function of patients with knee OA that appears not to be related to the radiographic severity of the OA or functional capacity. The OA effects are superimposed on the natural decline in muscle function seen with aging, with a greater impact at the longer muscle lengths.

## ACKNOWLEDGEMENTS

The authors acknowledge the technical support of M. L. Wilson, J. O'Connell and S. Ryer-Calvin. This study was supported by a grant from the National Institute on Disability and Rehabilitation Research.

## REFERENCES

1. Anderson, J. J. & Felson, D. T.: Factors associated with

osteoarthritis of the knee in the first national health and nutrition examination survey (HANES I). Am J Epidemiol *128:* 179–189, 1988.

2. Beals, C. A., Lampman, R. M., Banwell, B. F., Braunstein, E. M., Albers, J. W. & Castor, C. W.: Measurement of exercise tolerance in patients with rheumatoid arthritis and osteoarthritis. J Rheumatol *12:* 458–461, 1985.
3. Convery, F. R. & Minteer-Convery, M.: The knee. *In* Principles of physical medicine and rehabilitation in the musculoskeletal diseases (eds. J. C. Leek, M. E. Gershwin & W. M. Fowler, Jr.), pp. 453–488. Grune & Stratton Inc., Orlando, 1986.
4. Felson, D. T., Anderson, J. J., Naimark, A., Walker, A. M. & Meenan, R. F.: Obesity and knee osteoarthritis: the Framingham study. Ann Intern Med *109:* 18–24, 1988.
5. Felson, D. T., Naimark, A., Anderson, J., Kazis, L., Castelli, W. & Meenan, R. F.: The prevalence of knee osteoarthritis in the elderly. The Framingham osteoarthritis study. Arthritis Rheum *30:* 914–918, 1987.
6. Fisher, N. M., Gresham, G. E., Abrams, M., Hicks, J., Horrigan, D. & Pendergast, D. R.: Quantitative effects of physical therapy on muscular and functional performance in subjects with osteoarthritis of the knees. Arch Phys Med Rehabil *74:* 840–847, 1993.
7. Fisher, N. M., Gresham, G. E. & Pendergast, D. R.: Effects of a quantitative progressive rehabilitation program applied unilaterally to the osteoarthritic knee. Arch Phys Med Rehabil *74:* 1319–1326, 1993.
8. Fisher, N. M., Gresham, G. E. & Pendergast, D. R.: Quantitative progressive exercise rehabilitation for osteoarthritis of the knee. Phys Med Rehabil Clinics North America *5:* 785–802, 1994.
9. Fisher, N. M., Pendergast, D. R. & Calkins, E.: Muscle rehabilitation in impaired elderly nursing home residents. Arch Phys Med Rehabil *72:* 181–185, 1991.
10. Fisher, N. M., Pendergast, D. R. & Calkins, E.: Maximal isometric torque of knee extension as a function of muscle length in subjects of advancing age. Arch Phys Med Rehabil *71:* 729–734, 1990.
11. Fisher, N. M., Pendergast, D. R., Gresham, G. E. & Calkins, E.: Muscle rehabilitation: its effect on muscular and functional performance of patients with knee osteoarthritis. Arch Phys Med Rehabil *72:* 367–374, 1991.
12. Gerber, L. H. & Hicks, J. E.: Rehabilitation in the management of patients with osteoarthritis. *In* Osteoarthritis: diagnosis and management (eds. R. W. Moskowitz, D. S. Howell, V. M. Goldberg & H. J. Mankin), pp. 287–315. WB Saunders, Philadelphia, 1984.
13. Gresham, G. E.: Traditional approaches to functional assessment in arthritis. J Rheumatol 14 (Suppl 15): 11–14, 1987.
14. Gross Portney, L. & Watkins, M. P.: Foundations of clinical research: applications to practice, pp. 115–117. Appleton & Lange, Norwalk, 1993.
15. Haffajee, D., Moritz, U. & Svantesson, G.: Isometric knee extension strength as a function of joint angle, muscle length and motor unit activity. Acta Orthop Scand *43:* 138–147, 1972.
16. Jette, A. M.: Functional status index: reliability of a chronic disease evaluation instrument. Arch Phys Med Rehabil *61:* 395–401, 1980.
17. Kellgren, J. H. & Lawrence, J. S.: Radiological assessment of osteo-arthrosis. Ann Rheum Dis *16:* 494–502, 1957.
18. Kellgren, J. H., Lawrence, J. S. & Bier, F.: Genetic factors in generalized osteo-arthrosis. Ann Rheum Dis *22:* 237–255, 1963.
19. Krebs, D. E., Staples, W. H., Cuttita, D. & Zickel, R. E.: Knee joint angle: its relationship to quadriceps femoris activity in normal and postarthrotomy limbs. Arch Phys Med Rehabil *64:* 441–447, 1983.
20. Lankhorst, G. J., van de Stadt, R. J. & van der Korst, J. K.: The relationships of functional capacity, pain, and isometric and isokinetic torque in osteoarthrosis of the knee. Scand J Rehab Med *17:* 167–172, 1985.
21. Lankhorst, G. J., van de Stadt, R. J., van der Korst, J. K., Hinlopen-Bonrath, E., Griffioen, F. M. M. & de Boer, W.: Relationship of isometric knee extension torque and functional variables in osteoarthrosis of the knee. Scand J Rehab Med *14:* 7–10, 1982.
22. Lindh, M.: Increase of muscle strength from isometric quadriceps exercises at different knee angles. Scand J Rehab Med *11:* 33–36, 1979.
23. Moskowitz, R. W.: Introduction. *In* Osteoarthritis: diagnosis and management (eds. R. W. Moskowitz, D. S. Howell, V. M. Goldberg & H. J. Mankin), pp. 1–6. WB Saunders, Philadelphia, 1984.
24. Murray, M. P., Duthie, E. H. Jr., Gambert, S. R., Sepic, S. B. & Mollinger, L. A.: Age-related differences in knee muscle strength in normal women. J Gerontol: Biol Sci *40:* 275–280, 1985.
25. Németh, G., Ekholm, J., Arborelius, U. P., Schüldt, K. & Harms-Ringdahl, K.: Hip joint load and muscular activation during rising exercises. Scand J Rehab Med *16:* 93–102, 1984.
26. Nordesjö, L.-O., Nordgren, B., Wigren, A. & Kolstad, K.: Isometric strength and endurance in patients with severe rheumatoid arthritis or osteoarthrosis in the knee joints. A comparative study in healthy men and women. Scand J Rheum *12:* 152–156, 1983.
27. Rudd, E.: Physiatric management of osteoarthritis. Clin Rheum Dis *11:* 433–445, 1985.

*Accepted January 23, 1997*

*Address for offprints:*

Nadine M. Fisher, EdD
Rehabilitation Physiology Laboratory
Department of Rehabilitation Medicine
State University of New York at Buffalo
Erie County Medical Center
462 Grider St.
Buffalo, New York 14215
USA