Quadriceps function, proprioceptive acuity and functional performance in healthy young, middle-aged and elderly subjects

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Abstract

Background: muscle functions to generate force-producing movement and also has a role in proprioception. If ageing compromises these sensorimotor functions of muscle, the ability of older subjects to detect and correct postural sway may be impeded, resulting in impairment of functional performance.

Method: to see if age-related changes occurred and, if so, what their effects might be. Quadriceps strength, proprioception, postural stability and functional performance were assessed in young (n = 20, mean age 23 years), middle-aged (n = 10, mean age 56 years) and elderly (n = 15, mean age 72 years) subjects.

Results: with increasing age there were decreases in quadriceps strength (r = -0.511; P < 0.001), acuity of joint position sense (r = -0.603; P < 0.001) and postural stability (ANOVA < 0.002) during stance conditions which placed a greater reliance on muscle proprioceptors. These changes may decrease postural stability confidence, resulting in impaired performance of common activities of daily living (r = 0.635; P < 0.001).

Conclusions: the age-related deterioration in sensorimotor function of muscle may contribute to the increased fear and frequency of falls in elderly subjects, thereby decreasing independence.

Keywords: age-related changes, functional performance, muscle strength, proprioception, quadriceps

Introduction

As people age the force or torque produced during a muscle contraction (i.e. their muscle strength) decreases [1-5]. This muscle weakness may be caused by an age-related reduction in the number of muscle fibres [4], cross-sectional area of the muscle [5] or reduced voluntary activation [6]. Training studies have demonstrated that these strength deficits are partially reversible [2, 7, 8].

Apart from force generation, muscle is also an extremely important organ of proprioception. Proprioception may be defined as the conscious and unconscious awareness of body position, movement and forces acting on the body. It requires the integration of sensory information from peripheral proprioceptors (muscle spindles, Golgi tendon organs, articular and cutaneous mechanoreceptors), vision and the vestibular apparatus. At any age, input from the peripheral proprioceptors is the most important sensory component contributing to proprioceptive acuity [9-11]. Moreover, muscle spindles are the peripheral proprioceptors that impart the most important proprioceptive information [12-14]. Therefore an age-related impairment of muscle function may not only cause muscle weakness, but also affect proprioceptive acuity. The sensitivity and acuity of peripheral proprioceptors has been investigated by assessing joint position sense (JPS). Several studies have demonstrated a decrease in JPS acuity with ageing [15-17].

Postural stability has also been used to assess proprioception [11]. Postural stability requires the perception and integration of afferent information from the physiological systems involved in proprioception, as well as precise motor control to maintain postural equilibrium. The decline in postural stability associated with ageing [9, 18, 19] may reflect a decrease in the sensitivity and function of the
sensorimotor systems contributing to proprioception. Moreover, decreased postural stability increases the risk of falling [20], with the subsequent personal and socio-economic consequences of injury and loss of independence.

The quadriceps are extremely important for activities of daily living (ADL), including standing up, sitting down, stairs climbing and gait. Quadriceps weakness has been associated with decreased ADL performance and an increased incidence of falls in elderly subjects [21, 22].

This study compares quadriceps strength, activation proprioceptive acuity, postural stability and the performance of functional activities in young, middle-aged and elderly subjects.

Methods

Subjects

Twenty young (mean age 23 years, range 21–29 years), 10 middle-aged (mean age 56 years, range 50–64 years) and 15 elderly subjects (mean age 72 years, range 66–82 years) were assessed. All were healthy, active and living independently at home. A clinical examination of the knee and a validated assessment of knee function [23] were performed.

Subjects were excluded if they reported joint or muscle pain during testing, a history of lower limb trauma or degenerative joint disease, a Lequesne index [23] for the knee assessment > 4, neurological disease, vestibular disturbance or diabetes mellitus.

Measurement of isometric quadriceps force and activation

Quadriceps force

The subjects were seated on a chair constructed to measure quadriceps strength. Their hips and knees were flexed to 90°, and a restraining belt strapped across their waist to minimize unwanted hip, pelvic girdle and lower trunk movement. A non-extensible strap was placed around their lower leg just above the malleoli and the other end was attached to a strain gauge that was clamped onto the frame of the chair. The subjects were instructed to straighten their knee; since the non-extensible strap prevented joint movement an isometric maximum voluntary contraction (MVC) was produced. The signal from the strain gauge was amplified, processed by an A-D converter (CED, Cambridge, UK), displayed on a personal computer using Chart data handling software (CED) and collected for off-line analysis using Signal Averager software (CED). Three submaximal and three MVCs without electrical stimulation were performed to familiarize the patients with the procedures, but these values were not used in the data analysis.

Estimation of quadriceps voluntary activation

The degree of quadriceps voluntary activation was estimated by superimposing percutaneous electrical stimulation onto an isometric quadriceps MVC [24, 25]. With the subjects correctly positioned, two dampened electrodes were bandaged onto the proximal and distal aspects of the anterior thigh. A train of about 10 electrical stimuli (frequency 1 Hz, pulse width 50 μs, 400 V and 375 mA) were delivered through the electrodes. The amplitudes of five electrical stimuli delivered to the resting muscle were recorded, then the patient was instructed to perform the 4–5 s MVC while the stimuli train continued.

When the muscle is fully activated, the electrical stimulation does not generate additional force above the voluntary contraction. However, if the muscle is not fully activated additional force is generated by each electrical impulse: the smaller the force of the submaximal contraction, the greater the amplitude of the superimposed twitch. The reduced activation can be estimated by comparing the relative amplitude of the resting and superimposed twitches [26]. This technique stimulates about 60% of the muscle [24] and correlates well with percutaneous femoral nerve stimulation [24], which can produce near maximal muscle stimulation but is painful, poorly tolerated and unethical for human studies.

Three isometric quadriceps MVCs with superimposed electrical stimulation were recorded, but only data from the largest MVC were used in the analysis.

To facilitate full activation and generation of MVCs, each subject received a full explanation, was familiarized with the test procedures and was given vigorous verbal encouragement during the contractions, aided by real-time visual feedback of the force trace displayed on the computer monitor. After each MVC adequate recovery time was allowed to minimize fatigue.

Proprioception

JPS

In a quiet environment the subjects were blindfolded and seated on a chair with their hips and knees flexed to approximately 90° and their lower leg hanging independent. An electrogoniometer (Penny and Giles, Gwent, UK) was attached to lateral aspect of the subject’s knee using doubled-sided sticky tape. The proximal electrogoniometer block was placed just above the lateral femoral epicondyle in line with the greater trocanter, and the distal block just below the head of the fibula, in line with the lateral malleolus. In this 'resting position' the electrogoniometer display unit was set to 0. The subjects were instructed to
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slowly straighten their knee and told to stop at a random angle. This 'test angle' indicated on the display was noted. For approximately 5 s the subjects were asked to visualize their knee position. The subjects were then told to relax, allowing their leg to hang freely in the resting position, and after 3 s the subjects were asked to reproduce the test angle. The 'reproduced angle' on the display was recorded.

The procedure was performed for 10 test angles chosen randomly by the researcher throughout the range of 90° flexion and full knee extension. The mean error between the 10 test and reproduced angles was calculated.

Postural stability

Postural sway was assessed using a custom designed 'swaymeter' [27], which employed strain gauges to assess body sway when the subject stood on an aluminium force plate. The subjects stood in the centre of the plate with their feet placed slightly apart and arms by their sides, and they were instructed to remain as still as possible for 15 s. During this period the swaymeter assessed the amount of body sway and processed the data using custom written software, producing a value for postural stability in arbitrary units.

Three conditions of postural stability were assessed: bipedal stance with their eyes open, bipedal stance with eyes closed and monopedal stance with eyes open.

Functional performance

Timed walk

The subjects were asked to walk as fast as they could along a level, unobstructed corridor on the command 'Go'. A hand held stop-watch was started when the subject passed a pre-determined start mark, and stopped as they passed a second mark 15.48 m (50 feet) from the start mark.

'Get up and go' test [28]

The subjects were seated on a chair with arm rests, and instructed on the command 'Go' to stand up and walk along a level, unobstructed corridor as fast as they could. The stop-watch was started on the command and stopped when the subject passed the pre-determined mark 15.48 m (50 feet) from the chair.

Stairs ascent

The subjects stood at the bottom of a straight flight of stairs, consisting of eleven 12-cm-high steps, and asked to ascend the stairs as fast as they could on the command 'Go'. The stopwatch was started on the command and stopped when the subject placed their second foot down at the top of the flight of stairs.

Stairs descent

The subjects stood at the top of the flight of stairs. On the command 'Go' they were instructed to descend the stairs as fast as they could. The stop-watch was started on the command and stopped when the subject placed their second foot down at the bottom of the flight of stairs.

Aggregate functional performance time

To provide a more reliable measure of functional performance the aggregate time of all the individual functional performance tests, the aggregate functional performance time, was calculated.

Ethical approval

Ethical approval was obtained from the King's College London ethics committee. Each subject was given written information about the study and required to sign a consent form.

Data analysis

Differences of the parameters between the three age groups were assessed using one-way analysis of variance. If a statistical difference existed, Fisher's post hoc test was used to establish which group was different from the other groups. The degree of association between parameters was estimated using the Pearson correlation coefficient, r.

The data are presented as the mean with the 95% confidence interval (CI). The level of significance was set at P < 0.05. All tests are two-sided. Statistical testing was performed using 'Minitab' computer statistical software.

Results

Quadriceps force

The quadriceps of the elderly subjects were weaker (P < 0.001) than the young and middle-aged subjects (Figure 1). Quadriceps strength was negatively correlated with age (r = -0.511; P < 0.001).

Quadriceps activation

Quadriceps activation in age groups were 88.4% (CI 85.1-91.6%), 92.0% (CI 88.0-96.0%) and 90.6% (CI 86.7-94.6%) for the young, middle-aged and elderly subject groups respectively. There was no difference in quadriceps activation between the age groups.

There was no association between age and change in quadriceps activation (r = 0.063; P < 0.345).
Figure 1. Mean quadriceps strength in Newtons (N) for young (■), middle-aged (■) and elderly (□) subjects. Error bars show 95% confidence intervals. *Weaker ($P < 0.001$) than young and middle-aged.

Figure 2. Mean error of reproduction of joint position sense for young (■), middle-aged (■) and elderly (□) subjects. Error bars show 95% confidence intervals. *Less accurate ($P < 0.001$) than young and middle-aged.
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Figure 3. Mean postural stability of young (■), middle-aged (●) and elderly (□) subjects, during bipedal stance with eyes open and closed and during monopedal stance. Error bars show 95% confidence intervals. *Less stable (P < 0.002) than young. #Less stable (P < 0.005) than young and middle-aged.

JPS
The acuity of JPS in the elderly subjects was worse (P < 0.001) than the young and middle-aged subjects (Figure 2). As subjects’ ages increased, the acuity of JPS decreased (r = 0.603; P < 0.001).

Postural stability

Bipedal stance
In bipedal stance with eyes open, postural stability was similar in the three age groups (Figure 3). During bipedal stance with eyes closed, the middle-aged and elderly subjects were less stable (P < 0.002) than the young subjects (Figure 3).

Monopedal stance
The middle-aged and elderly subjects were unable to maintain monopedal stance for 15 s. Therefore the data collection period for these age groups was reduced to 7 s. Elderly subjects were less stable (P < 0.005) than the young and middle-aged subjects (Figure 3).

Functional performance
Although the middle-aged subjects were slower than the younger subjects in all the timed functional performance tests, the differences were not statistically different (Table 1). The elderly subjects were slower (P < 0.001) in all the individual tests (Table 1) and the aggregate functional performance time (P < 0.001; Figure 4) than the younger and middle-aged subjects.

The aggregate functional performance time increased as the subjects’ ages increased (r = 0.636; P < 0.001), quadriceps strength decreased (r = -0.37; P < 0.02) and acuity of JPS decreased (r = -0.535; P < 0.001).

Table 1. Time taken for the individual functional performance tests for each age group.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Mean (and 95% confidence interval) time taken, s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Get up and go</td>
</tr>
<tr>
<td>Young</td>
<td>10.5 (10.2–10.9)</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>11.2 (10.3–12.1)</td>
</tr>
<tr>
<td>Elderly</td>
<td>13.3 (11.8–14.8)*</td>
</tr>
</tbody>
</table>

*Slower (P < 0.001) than the young and middle-aged subjects.
Discussion

This study investigated the effect of age on muscle strength, JPS and postural stability, and whether these age-related changes affected performance of common ADL items. Although voluntary quadriceps activation did not change with age, there was an age-related decrease in quadriceps strength, proprioceptive acuity, postural stability and performance of simple functional ADL.

The age-related quadriceps weakness agrees with previous studies [1–5]. While the exact cause of this quadriceps weakness remains unclear, the similarity in voluntary activation between the age groups suggests it is not caused by an age-related reduction in voluntary activation [1, 29].

Proprioceptive acuity relies on accurate sensory input and central integration for which sensory information from muscle spindles is vital. Therefore factors which adversely affect muscle spindle sensitivity will decrease proprioceptive acuity. In this study assessment of JPS by active reproduction of limb position requires muscle contraction, this increases the fusimotor drive which heightens muscle spindle sensitivity and hence proprioceptive acuity [12, 13, 30, 31]. Thus, JPS was very accurate in the young subjects, but decreased with age. This age-related deterioration in JPS may be partially due to decreased muscle spindle sensitivity.

Proprioceptive acuity and precise neuromuscular motor control are essential for the maintenance of postural stability. Our older subjects were less stable than the younger subjects when visual input was removed (bipedal stance, eyes open) and the base of support decreased (monopedal stance, eyes open). These challenging stance conditions place greater reliance on the peripheral proprioceptors [11]. If ageing compromises muscle strength and muscle spindle sensitivity, the ability of older subjects to detect and correct postural sway may be impeded, resulting in decreased stability compared with the younger subjects.

With increasing age, the time required to process and integrate sensory information and motor reaction increases [10]. Therefore, decreased stability in older subjects is likely due to cumulative effects of minor deficits in the sensory, central processing and motor pathways, rather than impairment of a single component [32].

Muscle strength, proprioceptive acuity and postural stability contribute to mobility and confidence, enhancing the performance of common functional ADL. As these parameters deteriorated with age there was a trend for the older subjects to take longer to perform ADL. In addition, there were moderate, but significant, correlations between quadriceps weakness and decreased JPS acuity and increased aggregate functional performance time. Although correlation does not prove causation, these findings suggest muscle weakness and decreased proprioception may have a detrimental effect on functional performance.

People who habitually exercise are stronger, have faster reaction times and are more stable than people who do not exercise regularly [33]. Exercise regimes which increase muscle strength may also facilitate the neural pathways involved in proprioception, central processing and the acquisition of motor skills. This may account for some of the improvements in postural stability and functional performance following exercise programmes [34–36].

In summary, the age-related decrease in quadriceps strength was not caused by a reduction in voluntary quadriceps activation. Acuity of knee JPS and postural stability also decreased with age. Quadriceps weakness and decreased proprioceptive acuity in older subjects may contribute to a deterioration in postural stability.
These age-related changes in muscle function, combined with increased central processing reaction time, may contribute to the decreased confidence of older subjects and frequency of falling [22]. This may result in reduced mobility, performance of functional ADL and personal independence. Simple exercise regimes which promote strength, mobility and confidence may reduce the fear, risk and frequency of falls and consequent trauma, and restore the personal independence of elderly subjects.

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Key points

- Skeletal muscle functions to generate force and is an organ of proprioception.
- In healthy subjects, quadriceps strength, proprioceptive acuity, postural stability and performance of functional activities decreased with increasing age.
- Age-related deterioration in sensorimotor function of muscle may decrease confidence, increase the risk of falling and reduce independence.

References


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