Sensorimotor changes and functional performance in patients with knee osteoarthritis

Michael V Hurley, David L Scott, Joanne Rees, Di J Newham

Abstract

Objective—Muscles are essential components of our sensorimotor system that help maintain balance and perform a smooth gait, but it is unclear whether arthritic damage adversely affects muscle sensorimotor function. Quadriceps sensorimotor function in patients with knee osteoarthritis (OA) was investigated, and whether these changes were associated with impairment of functional performance.

Methods—Quadriceps strength, voluntary activation, and proprioceptive acuity (joint position sense acuity) were assessed in 103 patients with knee OA and compared with 25 healthy control subjects. In addition, their postural stability, objective functional performance (the aggregate time for four activities of daily living), and disabilities (Lequesne index) were also investigated.

Results—Compared with the control subjects, the patients with knee OA had weaker quadriceps (differences between group mean 100N, CI 136, 63N), poorer voluntary activation (20% CI 13, 25%) that was associated with quadriceps weakness, and impaired acuity of knee joint position sense (1.28°, CI 0.84, 1.73°). As a group the patients were more unstable (p=0.0017), disabled (10, CI 7, 11), and had poorer functional performance (19.6 seconds, CI 14.3, 24.9 seconds). The most important predictors of disability were objective functional performance and quadriceps strength.

Conclusions—In patients with knee OA, articular damage may reduce quadriceps motoneurone excitability, which decreases voluntary quadriceps activation thus contributing to quadriceps weakness, and diminishes proprioceptive acuity. The arthrogenic impairment in quadriceps sensorimotor function and decreased postural stability was associated with reduced functional performance of the patients.
impairment of functional performance and disability. These results were compared with data from a control group of healthy subjects with no knee abnormality.

Methods

Patients

Quadriceps function, postural stability, and functional performance were assessed in 103 patients (38 men) of mean age 61 years (range 28–83). Diagnosis of knee OA was made by a senior rheumatologist from the clinical history and physical examination of the patient. All the patients had knee pain and fulfilled the ACR criteria for knee OA. The patient’s age, sex, general medical history, history of knee complaint, knee pain (including duration, diurnal pattern, exacerbating and relieving factors), effusion, mechanical dysfunction and joint instability, deformities, presence and duration of knee stiffness, tenderness (medial, lateral, and patellofemoral), crepitus (tibiofemoral and patellofemoral), and bony swelling were recorded. The presence of bony changes was confirmed by anteroposterior and lateral weightbearing radiograms. However, it was not the aim of this study to examine the association between severity of clinical presentation and severity of radiological changes or compartmental involvement of knee OA, therefore the radiographs were not graded and no analysis of these associations were performed.

Forty six patients were not taking medication, 33 had been advised to take simple analgesia as required (for example, paracetamol or codeine only), and 24 were treated with non-steroidal anti-inflammatory drugs (NSAIDs, for example, diclofenac).

Sixty four patients had bilateral OA knee, data from the knee these patients considered was worst affected were used in the data analysis.

Patients who reported previous episodes of mild pain in other joints were included (for example, hands (n=22), hips (n=18), ankles (n=9), and spine (n=7)). Patients were excluded if they reported significant pain during the assessment procedures, or whose clinical examination or history revealed low back pain or symptomatic OA in ipsilateral or contralateral weightbearing joints (other than the contralateral knee) that might have influenced the results. Other exclusion criteria were unstable, co-existing medical conditions (for example, cardiovascular or neurological conditions; vestibular disturbance; diabetes).

As a comparative group, 25 healthy control subjects (seven men) were also assessed (mean age 65 years, range 50–82). They were recruited from local clubs and groups if they were in good general health and living independently in the community. None of the control subjects had a history of recurrent knee pain, and were excluded if they had a recent (within previous 12 months) single episode of knee pain or serious knee injury. Data were included from four control subjects with minor radiological changes but who were asymptomatic. The possibility that ‘volunteer bias’ may have affected the results cannot be discounted.

Table 1 gives anthropometric details of the patients and control subjects.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Patients (n)</th>
<th>Patients</th>
<th>Controls (n)</th>
<th>Control subjects</th>
<th>Difference between group means (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>103</td>
<td>60.73 (58.7, 62.73)</td>
<td>25</td>
<td>65.6 (61.66, 69.54)</td>
<td>4.9 (−9.5, 0.5)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>103</td>
<td>76.95 (74.09, 79.81)</td>
<td>25</td>
<td>73.96 (67.49, 80.43)</td>
<td>2.99 (−4.0, 10.0)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>103</td>
<td>1.65 (1.62, 1.66)</td>
<td>25</td>
<td>1.64 (1.61, 1.68)</td>
<td>0.01 (−0.05, 0.03)</td>
</tr>
<tr>
<td>Muscle function data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadriceps MVC (N)</td>
<td>103</td>
<td>235 (209, 261)</td>
<td>25</td>
<td>335 (308, 361)†</td>
<td>100 (136, 63)</td>
</tr>
<tr>
<td>Median quadriceps activation (%)</td>
<td>103</td>
<td>72.5 (66.95, 79.35)</td>
<td>25</td>
<td>93.0 (92.00, 95.00)†</td>
<td>20.5 (13, 25)</td>
</tr>
<tr>
<td>JPS mean error (degree)</td>
<td>69</td>
<td>3.57 (3.22, 3.92)</td>
<td>25</td>
<td>2.29 (2.00, 2.57)†</td>
<td>1.28 (0.84, 1.73)</td>
</tr>
<tr>
<td>Postural stability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bipedal stance, eyes open (degree)</td>
<td>80</td>
<td>0.120* (0.104, 0.136)</td>
<td>25</td>
<td>0.103* (0.086, 0.119)</td>
<td>0.024 (−0.005, 0.040)</td>
</tr>
<tr>
<td>Bipedal stance, eyes closed (degree)</td>
<td>76</td>
<td>0.237 (0.214, 0.260)</td>
<td>25</td>
<td>0.211 (0.178, 0.278)</td>
<td>0.026 (−0.012, 0.065)</td>
</tr>
<tr>
<td>Monopedal stance, eyes open (degree)</td>
<td>65</td>
<td>0.236 (0.222, 0.288)</td>
<td>25</td>
<td>0.233 (0.187, 0.278)</td>
<td>0.023 (−0.033, 0.078)</td>
</tr>
<tr>
<td>Functional performance data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APFT (s)</td>
<td>103</td>
<td>55.24 (50.70, 59.77)</td>
<td>25</td>
<td>35.62 (32.7, 38.6)†</td>
<td>19.62 (14.3, 24.9)</td>
</tr>
<tr>
<td>Median Lesquesne index</td>
<td>103</td>
<td>11 (10.42, 12.08)</td>
<td>25</td>
<td>11 (10.42, 12.08)</td>
<td>0.00 (0, 3.7)</td>
</tr>
</tbody>
</table>

JPS = joint position sense; APFT = aggregate functional performance time.

* Significantly more stable (p < 0.001) than bipedal stance with eyes closed and monopedal stance with eyes open.

† Significant difference (p < 0.0001) between patients and control subjects.
electrical stimulation upon isometric MVCs.\textsuperscript{14, 17} With the patients positioned as described above, two malleable electrodes (10 × 15 cm) were placed in a dampened sponge sleeve to improve electrical conductivity, which were then bandaged onto the proximal and distal aspects of their anterior thigh. A train of about 10 electrical stimuli (frequency 1 Hz, pulse width 50 μs, 400 volts, and 375 mA) were delivered through these electrodes. The amplitudes of five electrical stimuli delivered to the resting muscle were recorded (mean amplitude approximately 20–25% of the MVC), then the patient was instructed to perform a four/five second MVC as described above, while the stimuli train continued.

If the muscle is fully activated then electrical stimulation does not generate additional force. 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 extent of incomplete activation can be estimated by comparing the relative amplitudes of the resting and superimposed twitches.\textsuperscript{18} The coefficient of variation of this technique is approximately 8%.\textsuperscript{18, 19}

To minimise the patients apprehension, and facilitate full activation and the generation of MVCs each patient received a full explanation and was familiarised with the test procedures. In addition, during the contractions they were given vigorous verbal encouragement and aided by real time visual feedback of the force trace displayed on the computer monitor. Between each MVC a one minute recovery period was allowed to minimise fatigue. Three isometric quadriceps MVC with superimposed electrical stimulation were recorded, but only the largest MVC used in the data analysis.

During each quadriceps MVC and assessment of voluntary activation the patients were questioned about pain. If pain was reported they were asked to verbally rate the pain on a scale of 0–10 (0 = no pain, 10 = the worst pain they ever experienced in their knee). Although all the patients reported pain as a significant clinical feature of their knee condition, usually during weightbearing activities, the vast majority of patients (n=81, about 80%) tolerated the non-weightbearing assessments of quadriceps strength and activation extremely well, reporting no or very little pain. Patients who reported pain (n=30) were asked if they considered the pain was impeding muscle contraction; eight of these patients considered the pain was impeding their ability to produce an MVC, and as this was an exclusion criterion they were deemed unsuitable for participation in the trial.

**J}OYNT POSITION SENSE**

In a quiet environment the patients were blindfolded and seated on a high chair with their lower legs hanging relaxed and unsupported over the edge of the seat. An electrogoniometer (Penny and Giles, Gwent, UK) was attached to lateral aspect of the patients knee using double sided sticky tape. The proximal electrogoniometer block was placed just above the lateral femoral epicondyle in line with the greater trochanter, and the distal block just below the head of the fibula in line with the lateral malleolus. In this 'resting position' the electrogoniometer display was set to zero. The patients were instructed to slowly straighten their knee and told to stop at a random angle. This 'test angle' indicated on the display was noted. For approximately five seconds they were asked to maintain and mentally visualise the position of their knee. They were then told to relax, allowing their leg to hang freely in the resting position, and after three seconds the patients were asked to reproduce the test angle. The 'reproduced angle' on the display was recorded. The procedure was performed for 10 different test angles between 90° flexion and full knee extension. The mean error between the 10 test and reproduced angles was calculated. A previous report has shown this technique to be reliable and reproducible.\textsuperscript{20}

**POSTURAL STABILITY**

Postural stability, or body sway, was assessed by estimating the displacement of the patient’s centre of gravity (CoG) from the vertical. A custom designed 'swaymeter' consisting of a force plate with strain gauges and computer software was built.\textsuperscript{21} The patients stood in the centre of a force plate with their feet placed slightly apart, their arms by their sides, and asked to remain as still as possible for 10 seconds. For the first three seconds the mean position of the patient’s CoG was assessed, then for seven seconds the swaymeter traced the displacement of the patient’s CoG from this mean position. The software program estimated body sway by assuming the body behaved like an inverted cone with sway occurring at the ankles; the mean displaced CoG distance was the radius of the base of the inverted cone, and the height of the cone was the height of the patient’s CoG (calculated from the patient’s height), using these measures the mean angle of displacement of the CoG from the vertical can be calculated.\textsuperscript{21} The swaymeter produces a reliable estimation of postural stability with a coefficient of variance of 4%.\textsuperscript{20, 21}

Postural stability was assessed in three stance conditions, (a) bipedal stance with eyes open, (b) bipedal stance with eyes closed, and (c) monopedal stance on their affected leg with eyes open. During these stance assessments if patients tried to prevent over-balancing by grabbing a safety bar or placing their non-stance leg on the swaymeter during monopedal stance, the assessment was deemed unsuccessful and was repeated. Three attempts were permitted, if all three were unsuccessful the patient was deemed unable to perform that stance condition and the data excluded from the analysis of that stance condition. The number of patients who successfully completed each stance condition is shown in table 1.

**FUNCTIONAL PERFORMANCE**

*Fifty feet timed walk*\textsuperscript{22}

The patients were asked to walk as fast as they could along a level, unobstructed corridor on
the command ‘Go’. A hand held stopwatch was started as the subject passed a pre-determined start mark, and stopped as they passed a second mark 50 feet from the start mark.

The "Get up and Go" test
The patients 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 stopwatch was started on the command, and stopped when the subject passed a pre-determined mark 50 feet from the chair.

Stairs ascent
The patients stood at the bottom of a straight flight of stairs, consisting of 11, 12 cm high steps, and asked to ascend the stairs on the command 'Go'. The stopwatch was started on the command and stopped when the subject placed their second foot on the top step of the flight of stairs.

Stairs descent
The patients stood at the top of the flight of stairs. When instructed to descend the stairs the stopwatch was started on the command and stopped when the subject placed their second foot on the floor at the bottom of the stairs.

AGGREGATE FUNCTIONAL PERFORMANCE TIME
Any single test of functional performance imparts little information about the patients overall functional ability—that is, walking on a smooth floor gives little information about the dynamic balance required to stand up and walk across a room or ascend stairs. By aggregating the time of the four activities a better objective assessment of the patient’s overall functional capabilities can be obtained, this was called the aggregate functional performance time (AFPT).

LEQUESNE INDEX
The Lequesne index for knee OA is a pathology specific subjective assessment of disability. Patients were asked to rate their pain and ability to perform various ADL, scoring between 0 and 24 points. Lower scores indicate better subjective functional abilities. To investigate the relation of quadriceps strength and objective functional performance with disability, the Lequesne index was used to arbitrarily categorize the severity of the patient's disability as mild/moderate knee (Lequesne index <7), severe/very severe OA (Lequesne index >7 but <14), and extremely severe (Lequesne index >14).24

ETHICAL APPROVAL
Ethical approval was obtained from the King’s College Hospital Ethics Committee. Each subject was given written and verbal information about the study and signed a consent form.

DATA ANALYSIS
Level of significance was set at p<0.01. Statistical testing was performed using ‘Minitab’ version 10.2. All tests are two tailed.

For normally distributed data—that is, quadriceps MVC, JPS, postural stability, and AFPT—the data are presented as the mean with 95% confidence intervals (CI). Differences between these parameters of patients with knee OA and the healthy subjects, and between patient sub-groups, were assessed using unpaired t tests. The degree of association between these parameters was estimated using the Pearson correlation coefficient, r.

As the quadriceps activation was right skewed and the Lequesne index was ordinal data, these data are presented as the median with 95% CI. Differences between these parameters in the patients and healthy subjects, and between patient sub-groups were assessed using the Mann-Whitney test. The degree of association with these parameters was estimated using a non-parametric correlation—that is, Spearman’s rank correlation coefficient, rs.

Fisher's exact test was used to determine whether patients with knee OA had greater postural sway than the healthy subjects.

To investigate which variables explain most of the patient’s disability a multiple regression model was constructed with the Lequesne index as the dependent variable and age, body mass, quadriceps strength and activation, JPS, AFPT and bipedal stance with eyes open as the explanatory variables, and a forward stepwise regression analysis performed.

Results
QUADRICEPS MVC AND ACTIVATION
The patients with knee OA had weaker quadriceps than the control subjects, and could activate less of their quadriceps during an MVC (table 1). As the patient’s ability to activate their quadriceps decreased their quadriceps MVC also decreased ($r=0.486, p<0.001$; fig 1).

JOINT POSITION SENSE
To accurately assess knee JPS the patients had to actively extend their knee, maintain the test position for five seconds, and reproduce that angle for five seconds, so that a steady joint angle could be recorded. This was then repeated nine times at different angles. Unfortunately 34
patients found maintenance of steady knee position too difficult because of quadriceps weakness or poor control, therefore a reliable assessment of JPS was obtained for 69 patients only. Their mean error of JPS was greater—that is, they were less accurate—than the control subjects (table 1).

POSTURAL STABILITY
All the control subjects could maintain their balance for seven seconds during the assessment of postural stability. However, many patients were too unsteady to maintain stance for seven seconds, the numbers of patients who were able to perform each stance condition are shown in table 1. As a group patients with knee OA were less stable than the control subjects, this is shown by the numbers of patients unable to maintain bipedal stance with their eyes open for seven seconds (p=0.0017, Fisher’s exact test).

For any of stance condition there was no difference between the postural stability of the patients who could maintain that stance condition and the control subjects (table 1). The postural stability of these patients and the control subjects decreased when their visual field was removed or their base of support reduced (table 1).

There was no association between quadriceps strength or JPS and postural stability.

FUNCTIONAL PERFORMANCE AND DISABILITY
Objective assessment of functional performance
The patients were slower than the control subjects in all the individual tests of ADL (fig 2), and their aggregate functional performance time (AFPT) was greater (table 1). In the patient group there was an inverse relation between quadriceps MVC and their AFPT (r=−0.402, p<0.001)—that is, quadriceps weakness was associated with a deterioration in objective assessment of functional performance. The AFPT of patients with unilateral knee OA was better those with bilateral knee OA (table 2).

Disability
The median Lequesne index of the patients was greater than the control subjects (table 1)—that is, they were more disabled—and was inversely related to their quadriceps MVC (r=−0.385, p<0.001; fig 3A). When the Lequesne index was used to arbitrarily define the severity of the disability, the mean quadriceps strength (fig 3A) and AFPT (fig 3B) deteriorated as the severity of disability increased. Patients with bilateral knee OA were more disabled than patients with unilateral involvement (table 2).

There was a good correlation between the patient’s Lequesne index and objective assessment of functional performance, (r=0.665, p<0.001; fig 3B), therefore objective assessment of their functional performance reflects the patient’s subjective assessment of their functional ability.

Forward stepwise multiple regression indicated that AFPT and quadriceps strength accounted for 45% of the variance in the Lequesne index, but addition of other variables (that is, age, body mass, quadriceps activation, JPS, or bipedal stance with eyes open) to the model did not significantly influence the Lequesne index.

COMPARISON OF PATIENTS WHO COULD AND COULD NOT MAINTAIN BIPEDAL STANCE WITH EYES OPEN
The quadriceps MVC, activation and JPS of the patients who could maintain bipedal stance with eyes open for seven seconds were similar to the patients who could not maintain this stance condition. However, the AFPT and Lequesne index were worse in the patients who

Table 2  Comparison of the objective functional performance, the ASPT, and Lequesne index for disability of knee OA between male and female patients, patients with unilateral and bilateral knee OA, and patients who could not maintain bipedal stance with their eyes open for seven seconds

<table>
<thead>
<tr>
<th>Patients</th>
<th>Men</th>
<th>Women</th>
<th>Difference between group means</th>
<th>Unilateral knee OA</th>
<th>Bilateral knee OA</th>
<th>Difference between group means</th>
<th>Able to perform bipedal stance with eyes open</th>
<th>Unable to perform bipedal stance with eyes open</th>
<th>Difference between group means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean AFPT (s) (CI)</td>
<td>48.97 (42.3, 55.7)</td>
<td>48.0 (42.9, 53.1)</td>
<td>9.9 (−18.8, 27.6)</td>
<td>59.77 (53.4, 66.2)</td>
<td>11.77* (−0.385, p&lt;0.001)</td>
<td>51.96 (47.26, 56.66)</td>
<td>66.85 (55.5, 75.5)</td>
<td>12.89* (−27.3, −3.7)</td>
<td></td>
</tr>
<tr>
<td>Median Lequesne index (CI)</td>
<td>9.5 (7.5, 11.25)</td>
<td>12 (10.5, 12.75)</td>
<td>2.5 (−4.5, 9.7, 10)</td>
<td>12.5 (11.25, 13.5)</td>
<td>3.5* (−6, −2)</td>
<td>10.75 (8.75, 11.25)</td>
<td>14 (11.5, 16.0)</td>
<td>3.25* (−6.0, −1.5)</td>
<td></td>
</tr>
</tbody>
</table>

* Significant difference between the groups (p < 0.01).
could not maintain bipedal stance with eyes open (table 2), and as their postural sway increased there was a proportional increase in AFPT ($r=0.311$, $p<0.007$) and Lequesne index ($r=0.318$, $p<0.007$)—that is, poor balance was associated with reduced objective functional performance and disability.

INFLUENCE OF NSAID MEDICATION

To see if NSAID medication affected the assessment parameters, the data of the patients taking NSAIDs were analysed and compared with the patients who were not taking NSAIDs. There were no differences between any of the test parameters (that is, quadriceps strength and activation, JPS, AFPT, Lequesne index or postural stability tests) of these two patient groups.

Discussion

This study found that compared with healthy subjects, patients with knee OA have quadriceps weakness, decreased proprioceptive acuity, and poor postural stability, which were associated with a decrease in subjective and objective functional performance.

As healthy people age there is a decrease in quadriceps strength, but this is not caused

Figure 3  (A) Lequesne index and quadriceps strength of patients with knee OA. As quadriceps strength decreased the patient’s disability increased ($r=-0.385$, $p<0.001$). Mean quadriceps strength decreased in each arbitrarily defined category of disability ($p<0.001$). (B) Lequesne index and the aggregate functional performance time of the patients with knee OA. As the Lequesne index for disability increased the aggregate time of the tests increased ($r=0.665$, $p<0.001$). The mean AFPT increased at each arbitrarily defined level of disability ($p<0.001$).
by an age related reduction in voluntarily activation and patients with knee OA have a greater quadriceps weakness. Some of this disproportionate weakness may result from muscle atrophy as patient’s normal activities are restricted because of pain or decreased confidence, but this study shows that incomplete activation of their quadriceps during a volitional contraction will contribute to the weakness.

Joint pain and effusions are known to cause an arthrogenic reduction in activation. However, in this study during the assessments of quadriceps voluntary activation and strength the patients reported no pain or very mild pain, and none of them had clinical effusions. In these patients articular damage may stimulate articular mechanoreceptors evoking abnormal sensory information, which decreases voluntary activation. Afferent fibres from articular mechanoreceptors project (via intern neurones) onto α-motoneurones in the spinal cord, and these α-motoneurones activate extra-fusal muscle fibres. If articular damage evokes abnormal afferent information, which in turn decreases the excitability of α-motoneurones, this would reduce voluntary activation of the quadriceps. Articular mechanoreceptor’s afferent fibres also project onto γ-motoneurones in the spinal cord. γ-Motoneurones activate the intra-fusal muscle fibres that make up muscle spindles. Thus γ-motoneurone excitability governs muscle spindle sensitivity. If articular damage evokes sensory input that reduces γ-motoneurone excitability, this would decrease muscle spindle sensitivity and consequently decrease proprioceptive acuity.

Therefore damage of articular mechanoreceptors may impair both motor control (that is, voluntary muscle activation) and sensory appreciation (that is, JPS) in patients with knee OA.

The integrity of our sensorimotor systems is essential to effect a smooth, stable gait. Proprioceptive acuity ensures accurate timing and placement of the lower limb at heel strike, and eccentric quadriceps activity after heel strike minimises the affect of joint loading. It has been suggested that poorly controlled gait may be a factor predisposing knee OA. In vivo animal studies show that rapidly applied—that is, impulsive—loading of synovial joints causes cartilage destruction. In humans, mild knee pain has been associated with a habitual gait that involves high impulsive loading at heel strike, unfortunately it is difficult to ascertain whether pain causes increased impact loading or greater loading precedes pain. The quadriceps may have an important role in controlling impulsive forces at the knee at heel strike, as quadriceps paralysis of subjects who do not have knee pain increases the impulsive loading. Changed sensory input from articular mechanoreceptors may decrease quadriceps strength and proprioceptive acuity, impairing neuromuscular protective mechanisms that attenuate potentially harmful impact forces after heel strike, thereby accelerat-
sensorimotor function this may increase their confidence and promote personal independ-ence, alleviating the personal and socioeconomic burden of this disabling condition.

The authors are very grateful to the Arthritis and Rheumatism Council for their financial support of this project. We would also like to thank the staff in the Rheumatology Department of King’s Healthcare, London, for their help during this trial and in particular patients who gave up their time to participate. We are also very grateful to Matt Mills and Dave McInerney for technical help, and Dr Peter Milligan for his guidance with the statistical presentation of the results.


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