Joint Proprioception, Muscle Strength, and Functional Ability in Patients With Osteoarthritis of the Knee

M. van der Esch,1 M. Steultjens,2 J. Harlaar,3 D. Knol,4 W. Lems,2 and J. Dekker2

Objective. To test the hypotheses that poor knee joint proprioception is related to limitations in functional ability, and poor proprioception aggravates the impact of muscle weakness on limitations in functional ability in osteoarthritis (OA) of the knee.

Methods. Sixty-three patients with symptomatic OA of the knee were tested. Proprioceptive acuity was assessed by establishing the joint motion detection threshold (JMDT) in the anteroposterior direction. Muscle strength was measured using a computer-driven isokinetic dynamometer. Functional ability was assessed by the 100-meter walking test, the Get Up and Go (GUG) test, and the Western Ontario and McMaster Universities Osteoarthritis Index physical function (WOMAC-PF) questionnaire. Correlation analyses were performed to assess the relationship between proprioception, muscle strength, and functional ability. Regression analyses were performed to assess the impact of proprioception on the relationship between muscle strength and functional ability.

Results. Poor proprioception (high JMDT) was related to more limitation in functional ability (walking time r = 0.30, P < 0.05; GUG time r = 0.30, P < 0.05; WOMAC-PF r = 0.26, P < 0.05). In regression analyses, the interaction between proprioception and muscle strength was significantly related to functional ability (walking time, P < 0.001 and GUG time, P < 0.001) but not to WOMAC-PF score (P = 0.625). In patients with poor proprioception, reduction of muscle strength was associated with more severe deterioration of functional ability than in patients with accurate proprioception.

Conclusion. Patients with poor proprioception show more limitation in functional ability, but this relationship is rather weak. In patients with poor proprioception, muscle weakness has a stronger impact on limitations in functional ability than in patients with accurate proprioception.

KEY WORDS. Osteoarthritis; Knee; Disability; Proprioception; Muscle strength.

INTRODUCTION

Osteoarthritis (OA) is a widely prevalent, chronic, disabling condition. Clinically, OA of the knee is characterized predominantly by pain and limitations in the ability to perform activities of daily living, such as stair climbing, walking, and household chores (1). These limitations are partly due to muscle weakness (2–5). It has been suggested that functional ability is also affected by poor proprioception (6–13).

Knee joint proprioception encompasses the sense of joint position and the sense of motion. These senses partially derive from neural inputs arising from mechanoreceptors in joints, muscles, tendons, and associated tissue (7,14). Joint mechanoreceptors have the ability to detect the actual joint position and joint motion. Sensory feedback through knee joint mechanoreceptors, i.e., proprioception, modulates and activates knee muscles (15–17). Theoretically, knee joint proprioception is essential for accurate modulation and activation of muscles, thus providing adequate neuromuscular control of knee joint position and joint movement, and ultimately the performance of physical tasks. When proprioceptive acuity decreases, functional ability can only be maintained if there is sufficient muscle strength to compensate for the decrease in accuracy of modulation and activation of muscles. This implies that functional ability may be more...
strongly affected in the presence of both proprioceptive inaccuracy and muscle weakness.

Reduced proprioception has been reported in people with knee OA (7–13,18–23). Some studies have addressed the relationship between proprioception and functional ability in knee OA patients (8–13), but these studies showed conflicting findings. Some results suggest that deficits in proprioception are not large enough to have an impact on disability (9,10), whereas other results suggest that poor proprioception is associated with worse functional status (8,11–13). Thus, we hypothesized that proprioception is directly associated with limitation in functional ability, and poor proprioception aggravates the impact of muscle weakness on limitation of functional ability.

PATIENTS AND METHODS

Patients. Sixty-three patients diagnosed with OA of the knee were included in the study. Patients were registered and recruited in an outpatient rheumatology rehabilitation clinic in The Netherlands. Inclusion criteria were age between 40 and 85 years, unilateral or bilateral knee OA diagnosed according to the clinical criteria of the American College of Rheumatology (24), and consent to participate in the study. Exclusion criteria were polyarthritis, the presence of rheumatoid arthritis or other systemic inflammatory arthropathies, knee surgery within the last 12 months or a history of knee arthroplastic surgery, intraarticular corticosteroid injections into either knee within the previous 3 months, and/or an inability to understand the Dutch language. There were no patients with a history of knee ligament deficiency in our study population based on medical file and information obtained from the patients themselves.

Measures. A series of demographic variables were obtained including age, sex, height, weight, and duration of complaints (Table 1). Radiographs of the knee were scored in a blinded fashion by an experienced radiologist using the grading scales proposed by Kellgren/Lawrence (25,26). Weight-bearing anteroposterior radiographs of the knee joints were obtained following the Buckland-Wright protocol (27). Average overall pain in the past week and current average knee pain were measured using a 100-mm visual analog scale.

Functional ability was assessed with 2 standardized physical performance-based tests (the 100-meter walking test and the Get Up and Go test) and a self-report questionnaire (Western Ontario and McMaster Universities Osteoarthritis Index [WOMAC]). The walking test required subjects to walk as fast as possible a total of 5 times continuously up and down a level 20-meter corridor. A stopwatch was used to measure the time it took to complete the 100-meter distance, commencing from a verbal cue to start walking to culmination of the 5th pass.

The Get Up and Go (GUG) test was performed as previously described by Hurley et al (10). To perform the test, subjects were seated in a standard-height chair with armrests. On the command “go” subjects stood up without help of their arms and walked along a level, unobstructed corridor as fast as possible. A stopwatch was used to measure the length of time it took the subject to get up from the chair and walk 15 meters. Patients wore their own shoes during testing and were permitted to use a cane if they required it for walking. A longer time to complete the GUG test represented greater functional limitations. The intraclass correlation coefficients (ICCs) for the intratester and intertester reliability were both 0.98 (28).

The Dutch version of the WOMAC was used (29). The WOMAC is a disease-specific measure of pain, stiffness,
and physical function for individuals with OA of the knee. The WOMAC physical function (PF), with a possible score range of 0–68, was used to assess self-reported physical function. Each item was scored on a 5-point Likert scale, with higher scores representing greater limitations in function. Reliability and validity of the WOMAC has been established (29), and the Dutch WOMAC-PF has an ICC of 0.92 (29).

Muscle strength was assessed for flexion and extension of the knee using an isokinetic dynamometer (EnKnee; Enraf-Nonius, Rotterdam, The Netherlands). Quadriceps and hamstring muscle strength were measured isokinetically at 60°/second. A single tester assessed all patients according to a standardized protocol. Patients were seated on a bench and secured to the testing device through the use of chest, pelvis, and thigh straps. The ankle pad of the dynamometer was placed 2 cm proximal to the medial malleolus to allow ankle dorsal flexion during the tests. The mechanical axis of the dynamometer was aligned with the axis of the knee through the lateral epicondyle of the femur. Patients rested their hands on the sides of the bench.

During isokinetic testing at 60°/second, range of motion was limited to 20–80° to protect the knee joint. Following instruction, patients performed 4 warm-up repetitions, beginning with submaximal contractions and building to maximal contractions. Following a 30-second rest, patients performed 3 maximal test repetitions. Right-left order of testing was alternated between patients. During testing, the patient placed their hands on the sides of the isokinetic dynamometer to avoid compensatory movement of the trunk. The tester verbally encouraged the patients to achieve maximal torque. The mean strength for the quadriceps and hamstring muscles (in Nm per kg of body weight [Nm/kg]) of the right and left maximum voluntary contraction obtained from 3 measurements was used for analysis. The mean of the right and left knee was averaged to obtain a measure for total muscle strength around the knee at the patient level (4,30).

Knee joint proprioception was assessed using a knee joint motion detection task. Proprioception was measured as the threshold for detection of knee joint motion, expressed as the joint motion detection threshold (JMDT) (11). A device was constructed, consisting of a left and right stepper motor, a left and right transmission and linkage system, seating adjustment components, left and right angular displacements, 2 force transducers, and 2 stop buttons. This device provided knee angular displacement and precise measurement of the angular displacement with a resolution of 0.1°. Visual and auditory stimuli, mechanical vibrations, cutaneous tension, and pressure cues were minimized. The method of assessing proprioception was based on those described in the studies of Sharma et al (8) and Pai et al (11).

Subjects were seated in a chair with a back support, and both lower legs were supported on 2 separate lever arms (Figure 1). The chair was in a semi-reclined position. Each subject was seated with the knees at 90° flexion and the hips in 70° flexion. The knees were hanging over the edge of the chair, which was 5 cm proximal to the popliteal fossa. The axis of rotation was aligned with the tibiofemoral joint’s axis of rotation. An ankle cuff strapped around the lower leg, just above the malleoli minimized extraneous movements. To eliminate any contribution from cutaneous receptors and to avoid skin contact with clothing and the lever arm, the lower leg was placed on a free moving foot rest, which is a component of the lever arm. To minimize visual cues, patients were sitting behind an upward-bending tray, which prevented them from seeing movement of their knees. A stepper motor with low resonance and vibration was used to minimize auditory and vibration cues, and patients were seated on a thick cushion to eliminate vibration cues.

Each subject was given standard instructions informing them that a random leg would be tested. Both legs were moved to a starting position of 30° knee flexion. After stopping the movement, a random delay occurred before motion onset. Following this delay, computer-controlled constant angular motion of 1 knee was initiated at a velocity of 0.3°/second. The patient pushed a button after definite detection of knee joint position change: the right button after detecting knee joint position change in the right knee and the left button for the left knee. Each subject underwent several practice trials. The order of the leg tested was randomly chosen. The angular displacement
between the starting position and the position at the instant of pushing the button was recorded. The threshold for detection of knee joint movement was defined as the difference, in degrees, between the actual onset of motion and the subject’s detection of knee joint position change or motion. High JMDT meant a great difference between the actual onset of motion and the subject’s detection, and expressed poor proprioception. Low JMDT meant a small difference between the actual onset of motion and the subject’s detection and expressed accurate proprioception.

The mean JMDT of the right and left knees obtained from 3 measurements was used for analysis. The mean of the right and left knee was averaged, representing total proprioception (see Results section for further details). ICCs for intrarater reliability for the assessment of participants with and without OA by a single experienced tester were 0.91 and 0.87, respectively.

Statistical analysis. Because functional ability (i.e., walking time, GUG time, and WOMAC-PF score) was specific to the person, and muscle strength and proprioception were knee-specific data, a linear mixed model was used to account for the dependency of left and right knee data within subjects.

Pearson’s correlation coefficients were computed to establish the bivariate relationship between proprioception and muscle strength, between muscle strength and functional ability, and between proprioception and functional ability (i.e., walking time, GUG time, and WOMAC-PF score). A regression analysis was used to assess the relationship between muscle strength, proprioception, and functional ability. An interaction variable between muscle strength and proprioception was added to the regression analysis, to assess the role of proprioception as a modifier of the relationship between muscle strength and functional ability. To adjust for the dependency of proprioception of the left and right knees, the mean of both measurements and the difference between both measurements were added to the regression analyses. The same approach was used for muscle strength measurements of the left and right knees. This approach controls for the independent contribution to the regression model of the left and right knee data of proprioception and muscle strength, respectively. The variables proprioception and muscle strength were centered around the mean (31). Centering allows for a meaningful interpretation of main effects when interaction is present in the model. Other independent variables in the analysis comprised age, sex, duration of symptoms, and current pain. Results were considered statistically significant at \( P < 0.05 \). All analyses were performed using SPSS software, version 12.0 (SPSS, Chicago, IL).

RESULTS
The characteristics of the study sample are listed in Table 1. Mean ± SD proprioception, expressed as JMDT was 4.95° ± 2.98°. The mean ± SD JMDT in left knees was 4.76° ± 3.44°, and 5.14° ± 3.14° in right knees, with a Pearson’s correlation coefficient of 0.64 (\( P < 0.001 \)) between JMDT of the left and right knees. The median was 4.3°. The ICC for the 3 trials was 0.88 for the left knee, and 0.87 for the right knee. For that reason the mean of the 3 measurements was used in further analyses. A linear mixed model analysis of proprioception established variance in proprioception scores of 0.36 within subjects and 0.62 between subjects (ICC 0.63). This means that 63% of the variance in proprioception scores occurs between patients and 37% occurs at the knee level (within patients).

Mean ± SD total quadriceps strength was 0.99 ± 0.57 Nm/kg; in left knees the strength was 0.97 ± 0.62 Nm/kg and in right knees 1.02 ± 0.59 Nm/kg, with a Pearson’s correlation coefficient of 0.80 (\( P < 0.001 \)) between quadriceps strength of the left and right knee. Mean ± SD total hamstring strength was 0.67 ± 0.34 Nm/kg; in left knees the hamstring strength was 0.65 ± 0.34 Nm/kg and in right knees 0.69 ± 0.35 Nm/kg, with a Pearson’s correlation coefficient of 0.90 (\( P < 0.001 \)) between hamstring muscle strength of the left and right knee. Total muscle strength as an average of quadriceps and hamstring strength was 0.83 ± 0.45 Nm/kg, with a Pearson’s correlation coefficient of 0.94 (\( P < 0.001 \)) between quadriceps and hamstring muscle strength of the left knee and quadriceps and hamstring muscle strength of the right knee. A linear mixed model analysis of total muscle strength established variance within subjects of 0.12 and between subjects of 0.75 (ICC = 0.86). Mean ± SD walking time was 97.5 ± 35.6 seconds. GUG time was 13.6 ± 7.0 seconds, and WOMAC-PF score was 29.7 ± 14.1 with a theoretical maximum score of 68 points.

Bivariate relationships between JMDT, muscle strength, and functional ability. Poor proprioception (i.e., high JMDT) was related to greater limitation in functional ability (walking time \( r = 0.30, P < 0.05 \); GUG time \( r = 0.26, P < 0.05 \); WOMAC-PF \( r = 0.26, P < 0.05 \)). Poor proprioception (i.e., high JMDT) was associated with muscle weakness \( r = -0.42, P < 0.001 \). Muscle weakness was related to limitation in functional ability (walking time \( r = -0.66, P < 0.001 \); GUG time \( r = -0.61, P < 0.001 \); and WOMAC-PF score \( r = -0.55, P < 0.001 \)).

Multivariate relationships between JMDT, muscle strength, and functional ability. To analyze the relationship between functional ability, total muscle strength, and proprioception, a multiple regression model was constructed:

\[
\text{Functional ability} = b_0 + b_1 \times \text{muscle strength} + b_2 \times \text{proprioception} + b_3 \times \text{muscle strength} \times \text{proprioception}
\]

The difference between the left and right data of the variables proprioception and muscle strength did not add to regression model (Table 2). For that reason only the variables representing the mean score for proprioception and muscle strength at the patient level were used. The model explaining the total variation of walking time was as follows: walking time = 91.73 − 68.13 × muscle strength − 1.56 × proprioception − 11.61 × muscle strength × proprioception (\( F = 23.23, P < 0.001, R^2 = 0.54; N = 63 \)). This means that 54% of the total variation of walking time is explained by muscle strength, propriocep-
tion, and their interaction. Muscle strength ($b = -68.13$, $P < 0.001$) and the interaction between muscle strength and proprioception ($b = -11.61, P = 0.000$) were significantly associated with walking time. Thus, muscle weakness was found to be associated with more severe limitation in functional ability. In the presence of poor proprioception, muscle weakness was associated with even more severe deterioration of functional ability. When the mean proprioception (JMDT) of right and left knees equals 0 (0 = mean of 4.95°) and muscle strength decreases by 1 Nm/kg, then the walking time increases by 68.13 seconds. When the proprioception (JMDT) of right and left knees is 1° lower than the mean, and muscle strength decreases by 1 Nm/kg then the walking time increases by 56.52 seconds. However, when a decrease of muscle strength of 1 Nm/kg occurs in patients with 1° above the mean of proprioception (JMDT), then the walking time increases even more by 79.74 seconds.

The model explaining the total variation of the GUG time and the WOMAC-PF score is presented in Table 2. For GUG time, the results were similar to the results obtained with walking time. This means that muscle weakness was associated with a higher GUG time. In the presence of poor proprioception, muscle weakness was associated with even higher GUG time. Muscle strength was the only significant independent variable in the regression analysis on the WOMAC-PF score.

To visualize the interaction between muscle strength and proprioception, proprioception was dichotomized in poor proprioception (high JMDT) and accurate proprioception (low JMDT), using the median-split method. The demarcation between high and low JMDT was 4.3°. The results are shown in Figure 2.

These analyses were repeated in a more extensive model, with the demographic variables from Table 1 as controlling variables (age, sex, duration of symptoms, current pain). The results of those analyses showed that sex (women versus men) ($b = -28.90, P = 0.002$) added to the

<table>
<thead>
<tr>
<th>Variables†</th>
<th>Walking time‡</th>
<th>GUG§</th>
<th>WOMAC physical function¶</th>
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<tbody>
<tr>
<td></td>
<td>$b$ (SEE) $P$</td>
<td>$b$ (SEE) $P$</td>
<td>$b$ (SEE) $P$</td>
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<td>Intercept</td>
<td>91.73</td>
<td>0.000</td>
<td>11.91</td>
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<tr>
<td>Muscle strength</td>
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<td>-13.99 (1.70)</td>
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<tr>
<td>Proprioception</td>
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<td>0.225</td>
<td>-0.513 (0.24)</td>
</tr>
<tr>
<td>Muscle strength $\times$ proprioception</td>
<td>-11.61 (3.10)</td>
<td>0.000</td>
<td>-3.05 (0.59)</td>
</tr>
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* GUG = Get Up and Go test; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; $b =$ unstandardized regression coefficient; SEE = standard error of the estimate.
† Variables centered around the mean.
‡ $R^2 = 0.54, F = 23.23, P < 0.001$.
§ $R^2 = 0.57, F = 25.76, P < 0.001$.
¶ $R^2 = 0.30, F = 8.81, P < 0.001$.

Figure 2. Relationship between functional ability and muscle strength in an accurate proprioception (low joint motion detection threshold <4.3°) group and a poor proprioception (high joint motion detection threshold >4.3°) group. Sec = seconds; GUG = Get Up and Go test; WOMAC-PF = Western Ontario and McMaster Universities Osteoarthritis Index physical function. Dotted line and circle = poor proprioception group; solid line and triangle = accurate proprioception group.
explained total variation of walking time ($R^2 = 0.61, P < 0.000$). The inclusion of sex in the model did not affect the significance of the regression coefficients listed in Table 2. The addition of other control variables did not change the significance of the regression coefficients of muscle strength and proprioception. The results also showed that current pain ($\hat{b} = 3.02, P < 0.001$) added to the explained total variation of the WOMAC-PF ($R^2 = 0.54, P < 0.001$). However, current pain had no influence on the significance of the regression coefficients listed in Table 2.

**DISCUSSION**

We hypothesized that proprioception was related to functional ability in two ways. First, poor proprioception is directly related to limitation in functional ability. Second, poor proprioception aggravates the impact of muscle weakness on limitation of functional ability (i.e., walking time, GUG time, and WOMAC-PF score). Our results show that poor proprioception has a weak direct relationship with limitations in functional ability. This relationship was only present in bivariate analyses. In multivariate regression analyses, the main effect of proprioception on functional ability was not significant for walk time and WOMAC-PF score, and although statistically significant, the main effect of proprioception on GUG time was minimal. Thus, the direct effect of proprioception on functional ability can be considered to be weak. However, the interaction between muscle strength and proprioception contributed significantly to the variance in functional ability (i.e., walking time and GUG time, but not WOMAC-PF). These results suggest that in the absence of adequate motor control through a lack of accurate proprioceptive input, muscle weakness affects a patient’s functional ability to a greater degree.

Using a similar measurement of proprioception, Pai et al (11) found a significant correlation ($r = 0.367, P = 0.030$) between proprioception and the WOMAC-PF score, which is in agreement with our bivariate results. A comparison with other studies is hampered by differences in measurement protocols, equipment, and statistical analyses (9,10,13,32,33). The main difference is the operationalization of proprioception. Some studies used joint motion sense as a measure of proprioception (8,11), whereas other studies used joint position sense (9,10,13,32,33). In our study, proprioception was measured as joint motion sense. Therefore, it is difficult to compare the results of our study with those of studies that used joint position sense as a measure of proprioception.

To our knowledge, this is the first study to evaluate the impact of proprioception on the relationship between muscle strength and functional ability. It was theorized that knee joint proprioception is essential for accurate modulation and activation of muscles. When proprioceptive acuity decreases, functional ability can only be maintained if there is sufficient muscle strength to compensate for the decrease in accuracy of modulation and activation of muscles. Thus, it was predicted that functional ability will be more strongly affected in the presence of both proprioceptive inaccuracy and muscle weakness. In support of this theory, we found larger differences in functional ability due to differences in muscle strength in patients with a poor proprioception, compared with patients with accurate proprioception. Although the direct relationship between proprioception and functional ability is weak, it appears that proprioception indirectly influences functional ability through modulation of the relationship between muscle strength and functional ability.

It can be hypothesized that proprioception can be compensated by adequate muscle strength; in patients with poor proprioception, an increase of muscle strength would result in a bigger improvement in functional ability than in patients with adequate proprioception. If this hypothesis can be proven, this would support the use of exercise therapy in OA patients with poor proprioception. Although exercise therapy has been found to be effective in patients with knee OA, this does not apply to all patients with knee OA (2,3). Identifying subgroups of patients expected to benefit more from exercise therapy would increase the efficiency of care. Based on the results presented here, it can be hypothesized that patients with poor knee proprioception may benefit more from interventions aimed at increasing muscle strength. Patients with poor proprioception may have more benefit from exercise therapy than patients with adequate proprioception.

Poor proprioception is not a local process. In a study of patients with unilateral OA, Sharma et al found no between-knee difference in proprioception, suggesting that proprioception is a more generalized process (8). Our results seem to support this conclusion. Although we found a difference in proprioception between left and right knees, 63% of the variance in proprioception occurred at the patient level. Furthermore, in the multivariate analyses on the relationship between proprioception, muscle strength, and functional ability, the difference between left and right knees did not contribute to the regression model. Although proprioception differs between left and right knees, poor proprioception seems to be predominantly the result of generalized processes.

It is useful to consider some limitations of our study. One limitation is that the cut-off between adequate (i.e., low JMDT) and poor (i.e., high JMDT) proprioception is unknown. In our multivariate analyses continuous data were used. Scatter plots were provided to visualize the results in low and high JMDT groups. The JMDT data were dichotomized by the median-splitt method (median 4.3°). High JMDT (i.e., > 4.3°) means a great difference between the actual onset of motion and the subject’s detection, expressing poor proprioception. Low JMDT (i.e., <4.3°) means a small difference between the actual onset of motion and the subject’s detection, expressing accurate proprioception. It should be noted, however, that it is not known whether the cut-off value of 4.3° is clinically meaningful. The second limitation of our study was that it was a cross-sectional study, meaning causal conclusions were not allowed.

In a previous study on knee joint laxity in OA (34), patients with high knee joint laxity showed a stronger relationship between muscle strength and functional ability than OA patients with low knee joint laxity. This suggests that high knee joint laxity and impaired proprio-
tion have a similar influence on the relationship between muscle strength and functional ability. It should be noted that joint laxity measured in the present study was not significantly correlated with joint proprioception (r = 0.083, P = 0.515; [data not shown]). This indicates that different processes are responsible for the relationships found in these 2 studies. In conclusion, patients with poor proprioception show more limitation in functional ability, but this relationship is rather weak, and in patients with poor proprioception, muscle weakness has a stronger impact on limitations in functional ability than in patients with accurate proprioception.

**REFERENCES**