The role of joint afferents in sensory processing in osteoarthritic knees

H.-T. Weiler, G. Pap and F. Awiszus

Otto-von-Guericke-Universität Magdeburg, Neuromuscular Research Group at the Department of Orthopaedics, Leipziger Strasse 44, 39120 Magdeburg, Germany

Abstract

Objective. To test the role of joint receptors for proprioception in patients with bilateral knee osteoarthritis (OA) and patients who had undergone unilateral total knee arthroplasty (TKA).

Methods. Nine patients were tested bilaterally with a conventional movement detection paradigm that evaluated conscious detection perception and a newly developed hunting paradigm that measured maximal sensory performance (hunting perception).

Results. For detection perception, patients exhibited a slightly lower threshold on the arthritic side than on their TKA side. For hunting perception, the patients showed threshold values that were an order of magnitude smaller than for the conventional paradigm in both knees. Performance was much better on prosthetic knees than on OA knees.

Conclusion. The joint receptors of OA knees might have an adverse effect on the maximal proprioceptive performance, being important for the normal reflexive knee joint functions. These deficits may be overcome by joint receptor removal during knee replacement.

Key words: Proprioception, Total knee arthroplasty, Osteoarthritis, Knee, Joint receptors, Movement detection.

Introduction

The proprioceptive performance of patients suffering from osteoarthritis (OA) of the knee joints has been described in several publications as mild to severely impaired [1–5]. Impaired proprioception has been hypothesized as one of several reasons for the initiation and progression of osteoarthritis [2, 4–8]. The increasing pain and disability caused by knee osteoarthritis often leads to radical operative intervention in the form of total knee arthroplasty (TKA). Recent publications have referred to the importance of sparing joint receptors in TKA [1, 9, 10]. This is surprising, since muscle spindles and not joint receptors have been seen as the most important components of the proprioceptive system [11–15]. Joint receptors respond preferably at extreme joint positions. Muscle spindles register the information regarding body position and motion that is necessary for smooth movements.

Thus, the question arises of the role of joint receptors in proprioceptive performance in OA. Is their presence in OA of benefit and should their removal be prevented in TKA as far as possible? In order to answer these questions, we have investigated proprioceptive performance with a commonly used movement detection test [16–22]. The difference in angular degrees between the real and perceived onset of movement (about 1°) in this threshold detection test can be seen as a measure of one aspect of proprioceptive performance, detection perception.

Recently, we have developed a new way to measure the threshold of movement detection using a threshold hunting paradigm. The paradigm revealed very small threshold values for angular displacement. Healthy adult subjects showed a threshold value of 0.1° with movement velocities of 0.1°s⁻¹ [23]. Given that muscle spindles are the receptors responsible for movement detection, for theoretical reasons movements of 0.01° should be detectable [24, 25]. Thus the performance measured with the hunting paradigm reflects more the performance of the receptors than the outcome of the central processing of the sensation. In other words, this measure, values for which were one order of magnitude smaller than those for detection perception performance, reflects a performance that is more related to an earlier state in the sensory order of perception [26, H.-T. Weiler and F. Awiszus, submitted for publication]. Differences in vulnerability in different states should give insight into the nature of the role of joint afferents in sensory processing in OA patients.

Therefore, the present study investigated the proprioceptive performance of patients with two OA knees, one with joint receptors and one without (TKA), using two methods of evaluating the detection of movement.
Patients and methods

Subjects

Proprioceptive detection performance was evaluated in nine patients with bilateral OA. The mean age of this group was $66.6 \pm 1.5$ (s.e.m.) yr, and there were two males and seven females. One of the knees of each patient had received TKA (Natural Knee	extsuperscript{©}, Sulzer Orthopedics, Apen, Germany). The interval after TKA at the time of testing was $62.2 \pm 2.0$ months (mean $\pm$ s.e.m.: range 54–69 months). For the other knee, all subjects fulfilled the following clinical criteria of the American College of Rheumatology (ACR) classification for OA of the knee: knee pain on most days of the previous month; crepitus; morning stiffness lasting $>30$ min; and age over 60 yr [27, 28]. The patients’ knee conditions were also evaluated with the Knee Society’s knee score (i.e. subscore A) [29]. Both knee joints, the operated and the OA knee, were tested. Subjects were tested first with the movement detection paradigm and then with the threshold hunting paradigm. The study was conducted with the informed consent of the subjects and with approval of our institution’s ethics committee.

The subject was instructed to relax the muscles of the test joint completely, and to concentrate on possible movements of the knee. To avoid external clues, the apparatus and the knee joints were screened from the subject’s vision and white noise was delivered via headphones.

Apparatus

The subject sat on a comfortable armchair with the legs hanging freely over the side of the seat. The foot and ankle of the leg being investigated were immobilized with a rigid inflated air splint reaching up to 10 cm distal to the knee joint. The splint was suspended and connected by a wire to a stepper motor. An internal pressure of 4 kPa (30 mmHg) in the splint ensured that the ankle remained fixed, whilst not occluding circulation. A second air cuff was used 10 cm proximal to the knee joint. The purpose of the cuffs was to minimize cutaneous sensation.

The test rig consisted of a metal frame in front of the subject. A winding drum was connected to the stepper motor at the top of the frame. As the stepper motor moved, the wire wound up (in the case of extension) or wound down (in the case of flexion) a movement may start, consisting of a movement or an extension. During the subsequent observation interval, identified by a yellow light signal, the movement or sham movement was imposed. The order of testing for stimuli (flexions and sham movements) was distributed randomly with a probability of 0.5 for stimuli and sham stimuli. The correct detection of the direction of movement is important, as in many basic research publications the term ‘proprioception’ has been used properly only when the subject has been able to report the direction of the imposed movement [14, 17, 24, 25, 31–34].

Each run was started by a warning interval identified by a red light signal on a screen, indicating that after a short time (4 s) a movement may start, consisting of a flexion or an extension. During the subsequent observation interval, identified by a yellow light signal, the movement or sham movement was imposed. The order of testing for stimuli (flexions) and sham stimuli (extensions and sham movements) was distributed randomly with a probability of 0.5 for stimuli and sham stimuli. Within sham stimuli, the order of testing for extensions and sham movements was also distributed randomly with equal probability. Sham movements were intervals of no motions with a duration as long as related motions in test. A green light signal that appeared 500 ms after cessation of the observation interval indicated that the subject had to decide, without a time limit, whether a flexion had occurred during the yellow light period. Depending on this decision, a button had to be pressed. Immediately after the subject had made the decision, the joint was returned to the starting position (45°) at the rate of 1° s$^{-1}$ and the green light signal disappeared. The resetting movement was fast enough to be perceived clearly most of the time. If the response was correct, the yellow and green signals lit up briefly and thus served as reinforcement. If the response was wrong the yellow and red signals lit up. After each run the value of the subjects and proprioception in OA knees

Joint afferents and proprioception in OA knees

851
Data analysis
Go/stop detection paradigm. The distributions of the values of angular displacement for go and stop detection for prosthetic and OA knee joints were compared by the Kolmogorov–Smirnov test. The threshold values of angular displacement for go and stop detection (median of the six values) were compared by the Mann–Whitney rank sum test.

Hunting paradigm. The distributions of the values for the tested angular displacements for prosthetic and OA knee joints were compared by the Kolmogorov–Smirnov test. Individual hunting curves were analysed as described previously. The median of the minimal amplitude values, stored in a temporary file, which characterizes changes during the course of hunting towards larger values, was computed as the threshold value at the end of the session and was stored in a results file. Fifty trials were used to produce a stable hunting curve. More trials would not have improved the result because fatigue would have occurred. The first 15 values of an individual hunting curve were disregarded as these might have reflected training effects.

Results
The subjects had a median knee score of 88 (range 80–99). More pain was reported in the OA knee than in the TKA knee (TKA, median = 50; OA, median = 40; P = 0.03). No differences were reported between the two knees in muscle strength or fatigue. There was no correlation between pain and any other parameters tested (P = 0.11–0.82).

Figure 1 shows two hunting curves that are qualitatively similar but quantitatively represent the extremes. Figure 1A and B show results for a single 60-yr-old female patient. The detection of movement onset was earlier and more homogeneous for the OA knee (filled circles) than for the prosthetic knee (open circles) in the movement detection paradigm (Fig. 1A). The patient's hunting curve shows that she very consistently detected very small movements with her prosthetic knee but not with the OA knee (Fig. 1B). The shape of the curve shows two parts; the initial pattern is very similar for the two knees, since the patient reached a similar detection level with her two knees. The second part of the curve shows that with the OA knee she was unable to reach the level she attained with the prosthetic knee. Figure 1C and D show results for another 66-yr-old female patient. Whereas the results of the movement detection paradigm were very similar to those for the first patient (Fig. 1C), the shapes of the hunting curves differ drastically quantitatively, but not qualitatively (note the different ordinate scales) (Fig. 1D).

The results for the remaining patients were quantitatively more similar to those of the first patient than to those of the second patient. As can be seen in Fig. 2A, the distributions of the go detection values for all patients in the conventional movement detection paradigm for the OA side (continuous lines) were significantly different from the distributions for the TKA side (dashed line) (P = 0.001). A similar difference was found for the stop detection values (P < 0.001). On both sides, the go detection values did not differ from the stop values (P = 0.21 and 0.70). The distributions of amplitude values for the threshold hunting paradigm shown in Fig. 2B showed an opposite behaviour (P < 0.001).

The threshold values for the two paradigms are depicted in Fig. 3. The go detection threshold values (the median value of each individual leg) were slightly but significantly smaller on the OA side (median 1.12°, first quartile 0.94°, third quartile 1.24°) than on the TKA side (median 1.49°, first quartile 1.24°, third quartile 1.89°) (P = 0.027; Fig. 3A). The stop detection threshold values exhibited no statistically significant difference (P = 0.331; Fig. 3B). For both knees, the threshold values of the hunting paradigm were an order of magnitude smaller compared with the conventional movement detection paradigm. However, the threshold on the OA side (median 0.40°, first quartile 0.35°, third quartile 0.50°) was on average twice as large as the threshold on the TKA side (median 0.19°, first quartile 0.13°, third quartile 0.26°) (P = 0.024; Fig. 3C).

Discussion
Since proprioceptive performance was attributed to muscle spindles, all factors affecting the muscles could have affected the results. It is conceivable that the consequences of surgery, e.g. improved ambulation, intensive physical therapy, and therefore improved muscle strength and decreased pain, might have influenced the results. No consistent differences were found in muscle strength between the two knees in brief clinical tests, although more objective and precise testing of
muscle function, e.g. using the twitch interpolation technique, would be desirable [35, 36]. Patients reported no differences in fatigue. Self-reported fatigue might not be a sufficient criterion since muscle fatigue, a well researched area, has a well characterized methodology [37]. Because of the method we used to select the patients for the study, pain was reported more on the OA side than on the TKA side. Pain might increase the level of background firing of γ-motor neurons [38] and thereby increase the sensitivity of the muscle spindles. However, in a recent study in cats, increased γ-innervation was shown to be deleterious to proprioception [39]. Nevertheless, the pain score did not correlate significantly with any of the parameters that were measured. During test sessions no pain was reported and no analgesics were used. Therefore, despite methodological weaknesses in the measurement of muscle strength, fatigue and pain, even if there had been a difference in one of these parameters, this difference can explain, if indeed it can explain anything, the results found in either of the two paradigms, but not the dissociation between them.

Before discussing the results, it should be pointed out that not only were the hunting perception and detection perception values different in magnitude, but their trends followed opposite directions. Therefore, we can exclude the possibility that they were simply a phenomenon of scaling; they were qualitatively different. Moreover, the two sets of measurements were made with the same apparatus. Thus, possible differences cannot be attributed to different technical arrangements, since only the patients’ tasks were different.

Obviously, the standard perception test used to characterize detection perception performance [16–19] does not reflect the maximal performance level of the receptors in the periphery. Results of this test might be influenced to a large extent by some kind of cognitive processing, as has also been shown in a previous investigation [40].

The side differences found for the group of patients investigated here were conflicting. Considering the performance in detection perception of the present results, at first glance one may assume that the presence of joint receptors may be of benefit for the perception of passive motion, a result clearly in line with those of other groups [1, 10]. The most obvious explanation for this finding would be that joint receptors contribute in some way to the perception of passive motion. This simple hypothesis, however, was refuted by our results, in that the knees lacking joint receptors had a clearly lower hunting
Threshold values (median plus third quartile), based on the distributions of the two paradigms depicted in Fig. 2, for the OA side (filled columns) and the TKA side (open columns). (A) Detection perception in the conventional movement detection paradigm for movement onset (go detection). (B) Detection perception in the conventional movement detection paradigm for movement offset (stop detection). (C) Hunting perception in the threshold hunting paradigm.

Cumulative frequency (%)

Fig. 2. Cumulative distribution functions for values for all patients \( (n = 9) \) for two different paradigms measuring proprioceptive performance on the OA side (continuous line) and the TKA side (dashed line). Patients were tested with a conventional movement detection paradigm measuring detection perception. (A) Cumulative distribution functions, of the time intervals at which movement onset (go detection) was detected. (B) Cumulative distribution functions of the tested angular displacement values for a threshold hunting paradigm measuring hunting perception.

As joint-receptor-mediated perceptions can be excluded as the reason for the better detection perception performance of the receptor-bearing knee, there must be another explanation. First, one must consider that the replaced knee had been the clinically worse joint before the operation. Thus, it may well be the case that a larger perception deficit was present in the replaced knee before surgery and that this deficit had not vanished even after 5 years. Loss of sensory information leads to cortical reorganization, as is well known from studies in amputees [41]. A correlation of clinical state with proprioceptive performance has been described for OA patients [2, 4–8]. Interestingly, the presence of a side difference in performance in the perception of passive motion has been found to be highly correlated with a permanent central representation change of cortical potentials in patients with chronic deficiency of the anterior cruciate ligament [42]. Similar permanent cortical reorganization in our prosthetic patients would explain the observation that perception deficits may be present to an even greater extent when the knee is replaced.

As a second hypothesis, it may be assumed that joint receptor afferents, even if altered by chronic OA, may perform some kind of central gating for the perception of passive motion. Removal of these receptors by knee replacement would impair the gating mechanism, resulting in reduced performance in detection perception despite normal hunting perception.

As the joint receptors were completely removed on the TKA side, they can be excluded as a source of information. Therefore, the most probable information source for the measured hunting perception performance appears to be the muscle receptors, particularly the muscle spindles. Thus, the difference lies in the alteration in muscle physiology and function that accompanies knee replacement and subsequent rehabilitation. Thereby, improved ambulation and intensive physical therapy should improve muscle function bilaterally rather than just unilaterally. Unfortunately, not enough is known about muscle function to allow an explanation of this hypothesis. This, together with the objective measurement of pain and fatigue, should be the subject of further studies.

In summary, our results were contradictory. On the one hand, sensory sensation in replaced knees was not...
reduced peripherally, so that hunting perception (maximal proprioceptive performance) was still possible, and joint receptors were not responsible for this performance. Without joint receptors the central proprioceptive processing of perception appeared to be slightly disturbed. On the other hand, OA knees showed impaired hunting perception performance. Thus, the joint receptor of the OA knee might have an adverse effect on hunting perception even when it has an improving effect on central processing. Since the effect of joint receptors on $\gamma$-motor neurons has been demonstrated [43], the adverse effect of the ‘OA joint receptor’ might be seen in this function. Therefore, the removal of such altered receptors by TKA appears to be beneficial, because the maximal proprioceptive performance tested by the hunting paradigm may be important for reflexes and the physiology of gait. When making decisions about intervention, one has to choose between the preservation of the joint receptors in order to improve or preserve central processing, and their removal in order to improve or preserve maximal proprioceptive performance.

Acknowledgements

This work was supported by the Deutsche Forschungsgemeinschaft (Aw5–2/2).

References

15. Sherrington CS. On the proprioceptive system, especially in its reflex aspects. Brain 1906;29:467–82.


