Elbow joint position sense after total elbow arthroplasty

Przemysław Lubiatowski, MD, PhD, DSc*, Izabela Olczak, MA, Ewa Lisiewicz, MA, Piotr Ogoradowicz, MD, PhD, Maciej Bręborowicz, MD, PhD, Leszek Romanowski, MD, PhD, DSc

Background: Multiple human experiments have shown that articular lesions can have a negative effect on proprioception. The influence of total elbow arthroplasty on joint position sense has not been reported so far. The purpose of the study was to evaluate proprioception, defined as a joint position sense, after total elbow arthroplasty.

Methods: The study included 16 patients with unilateral semiconstrained linked total elbow arthroplasty and 21 healthy volunteers. The evaluation included measurement of active and passive reproduction of joint position sense of both elbows after surgery and the control groups. Reference angles included extension to 50° and 70° and flexion to 110°. We also assessed function of the elbow in arthroplasty group using the Mayo Elbow Performance Score, the Disability of the Arm, Shoulder and Hand score, and a visual analog scale for pain level.

Results: The average value of error of passive reproduction of joint position for elbows after arthroplasty was significantly inferior for all evaluated positions compared with the contralateral elbow and with the control group, respectively, at 110° flexion: 4.3°, 2.7°, and 3.2°; at 70° extension: 4.9°, 2.9°, and 2.7°; and at 50° extension: 6.3°, 3.8°, and 3.8°. The average value of error of active reproduction of joint position for the arthroplasty group was also significantly inferior, respectively, at 110° flexion: 3.5°, 1.9° and 2°; and at 50° extension: 4.4°, 3.3°, and 3°.

Conclusion: Proprioception in elbows that undergo total arthroplasty is significantly inferior compared with the contralateral site of the patient and in the healthy control group.

Level of evidence: Basic Science, Kinesiology.

Keywords: Joint position sense; proprioception; elbow; total elbow arthroplasty; osteoarthritis

Proprioception has been studied extensively throughout the past 2 decades. The first explorations were made more than a century ago with the pioneering work by Sherrington in 1906, when the term proprioception was introduced and defined. A more modern definition was formulated by Goble as the ability of an individual to determine body segment positions and movements in space and was based on sensory signals provided to the brain from muscle, joint, and skin receptors. In general, proprioception refers to the perception of joint position and movement and is part of neuromuscular control of the body parts (joints). Afferent information coming from the receptors localized in capsule, ligaments, tendons, muscles, and skin is further processed in the central nervous system on different levels (spinal cord, brain stem, cortex, and cerebellum). The
final response is reflex activation of stabilizing muscles in effort to obtain proper joint balance and stability. Joint position sense (JPS) has been one of the attributes of joint proprioception. Proprioception has been studied mostly with the potentially unstable elbow and shoulder. Numerous human experiments have shown that articular lesions can have a negative effect on proprioception. Others have proposed that inferior proprioceptive abilities contribute to abnormal loading and an increased risk of injury. Control of the non–weight-bearing elbow joint may also be specifically important for fine and precision tasks of the upper limb.

Proprioception of the elbow has not yet been extensively studied. To our best knowledge, no study has investigated elbow proprioception after total elbow arthroplasty (TEA). Only a few reports about proprioception after other joint replacements have been published. TEA is currently a reliable surgical option for patients with a broad variety of indications, including painful arthritis and comminuted distal humeral fractures. Although pain relief and an improved function is a significant and predictable advantage, the failure rates remain relatively high.

The function of the implant generally relies on the laxity of components, dynamic muscle support, and prosthetic alignment. The surgical approach is extensive, and damage to the soft tissues might be an issue. The capsule needs to be excised and muscle attachments around the elbow released. In theory, that has to affect elbow proprioception and neuromuscular control. The purpose of the study was to evaluate proprioception, defined as a JPS, after TEA.

Materials and methods

This was a retrospective case-control study. Data included patients with unilateral semiconstrained linked TEA with a minimum 2-year follow-up time after having been operated on in our institution between 2002 and 2012. Of 26 patients evaluated, 16 (10 women and 6 men) agreed to participate in the study and have been followed up retrospectively. All study participants signed appropriate consent.

The patients were an average age of 59.25 years (range, 38-84 years). The indication for surgery was rheumatoid arthritis in 9 patients, osteoarthritis in 2, and post-traumatic arthritis in 5. The right elbow was operated on in 9 patients and the left in 7, and the Bryan-Morrey triceps-sparing approach was used in all cases. The average follow-up time was 39.9 months (range, 24-84 months).

The control group for proprioception measurements consisted of 21 healthy volunteers who were an average age of 26 years (range, 20-30 years). Medical records showed no evidence of elbow problems or any neurologic disorders.

Evaluation was performed at the follow-up visit and included proprioception evaluation by measurement of the JPS of both elbows in TEA and in the control group. The TEA group was further evaluated for range of motion (ROM), pain level according to the visual analog scale (VAS), Mayo Elbow Performance Score (MEPS), and the Disability of the Arm, Shoulder and Hand (DASH) score.

Proprioception evaluation

Proprioceptive abilities were evaluated by the measurement of JPS. For that purpose, reproduction of the joint position (RJP), both active (ARJP) and passive (PRJP), was analyzed. The general idea is that patients reproduce actively and passively a presented reference joint position. The angles of reference and RJs were measured with the high-accuracy electronic goniometer. The absolute value of difference of reference and reproduced angles was analyzed as a measure of proprioceptive abilities. The difference has been called the error of ARJP (EARJP) or PRJP (EPRJP), depending on active or passive reproduction.

We used the Propriometer, a specific device developed previously in our institution (Progress Company, Ostrów Wielkopolski, Poland). This electronic goniometer, with an accuracy of 0.1°, consists of a transducer (based on the Earth’s magnetic field), a PC panel, and a remote. The personal computer (PC) panel is connected to the PC and is controlled with specific software that allows a proper recording and calculation of measurements.

To obtain a stable and undisturbed motion of the elbow, the patient was seated in a Biodex chair (Biodex Medical Systems, Inc, Shirley, NY, USA), and the upper limb was fixed into a hinged frame. For passive evaluation, the device moved the elbow in a continuous passive motion with constant speed of 2° per second. The transducer was placed on the Biodex moving frame, parallel to the forearm (Fig. 1, A).

For active evaluation, the transducer was placed on the forearm and the arm was placed parallel to the floor, resting on the Biodex frame (Fig. 1, B and C). The forearm was free, not supported, and fully controlled by the examinee.

For both modes, the person being examined held the remote in the opposite hand. The patient’s eyes were covered, and the room was silent. Reference positions (50°, 70°, or 110°) were presented passively and confirmed by pressing the remote button once the position was achieved and memorized. The reference angle was recorded in the PC unit. The forearm was repositioned to the starting angle of 90° flexion. The patient’s task was to reproduce the same position, extend it to 50° or 70°, or flex it to 110°. Once the patient achieved the position, then he or she pressed the button again to confirm it. The reproduced angle was recorded to the program and the error of reproduction of the joint position calculated. For active reproduction, the patient used his or her muscles to move the forearm to the desired position. For passive reproduction, the frame moved to allow passive elbow motion.

Five repetitions were performed for every reference position for the active and passive mode. An average of 5 measurements was calculated to get the final average error for each actively (EARJP) and passively (EPRJP) reproduced reference position.

Both elbows were evaluated for every study participant: affected and nonaffected elbows for the TEA group and both elbows for the control group. Preliminary calculations of the errors of the control group did not reveal significant differences in any measures when dominant and nondominant sites were compared. Therefore, results of both elbows were combined into one control group for further comparisons.

The protocol that was developed for this study was based on our previous experience with shoulder proprioception assessment. Current study methodology was modified for the evaluation of the elbow joint.
Statistical analysis was performed using StatPlus 2009 software (AnalystSoft Inc, Alexandria, VA, USA) and included normality tests, the analysis of variance, Spearman rank correlation coefficient, Mann-Whitney, and Student $t$ tests. The analysis included a comparison of results for affected, nonaffected (contralateral), and control elbows. We also tried to find possible correlations of JPS with other measurements, including ROM, flexion or extension contractures, functional ROM, MEPS, DASH, and history of revision.

**Results**

Results of EARJP and EPRJP are displayed in Figs. 2 and 3. Average values for the active and passive modes showed that elbows with TEA had significantly inferior JPS and active control compared with contralateral and with control elbows. No significant difference of JPS matching was found within the control group when dominant and nondominant elbows were compared nor when control group elbows were compared with contralateral elbows that had not been operated on.

We also compared ARJP and PRJP at the same reference position within all study groups. The active and passive mode was no different within the TEA elbows and contralateral elbows (Table I). Active control was superior to passive matching for flexion to a 110° position, and passive sense was superior to active control for extension to a 70° position in the control group. Most of the correlations of different clinical data with proprioception were not significant. There was barely a significant positive correlation of active reproduction for 110° flexion with a pain level and a negative correlation of it with the MEPS (Table II).

**Discussion**

Proprioception refers to the perception of joint position and movement and is part of neuromuscular control of the body parts (joints). A contemporary definition of proprioception had been formulated as the ability of an individual to determine body segment positions and movements in space and based on sensory signals provided to the brain from muscle, joint, and skin receptors. The JPS had been chosen for evaluation as one of the senses important for monitoring body actions. In simple terms, patients had a task to reproduce blindly the elbow joint position that had been presented to them before. Accuracy of reproduction was the final measure. The higher the error, the worse accuracy, and proprioceptive abilities could be stated.

Numerous previous studies found proprioception measured as JPS was inferior in unstable shoulder or knee joints. Unlike the knee or the shoulder, proprioception of the elbow has not yet been extensively studied. Most upper limb movements are devoted to fine and precision tasks that justifies the functionally of such methodology. Researchers have focused on different aspects of elbow proprioception and the effect of different factors, including normal elbow, anesthetized, soft tissue degeneration, neurogenic disorders, exercises, and throwing. To our best knowledge, no study has investigated elbow proprioception after TEA, and those studies with other joint replacements have not been numerous.

TEA is currently a reliable surgical option for patients with a broad variety of indications, although some treatment problems and complications might be challenging. Depending on the prosthetic design, the function of the implant relies...
on laxity of components, dynamic muscle support, and implant alignment. We have used a TEA prosthetic with a linked semiconstrained design in all our patients.

TEA is quite a traumatic surgery, with an extensile approach. Soft tissue damage is significant. First, medial then lateral skin flaps are partly raised. The triceps is reflected along with the forearm fascia. Both flexor and extensor origins are released from the epicondyles. Collateral ligaments are also released, and the capsule is excised. This means that significant damage to the main tissue sources of proprioceptive afferentation, including skin, capsule, muscle, and tendon can be expected.

The importance of a particular receptor contribution to JPS is not clear. Muscle spindles provide feedback in response to centrally generated motor actions and trigger motor adjustments in reaction to unexpected loads or obstacles, being particularly important when the limb is actively controlled. For passive movements, other components of proprioception probably have a major contribution. Tendons are believed to provide the sense of tension. Significance of capsular mechanoreceptors is not

Table I Comparison of results active vs passive of errors of the reproduction of the joint position by Mann-Whitney test

<table>
<thead>
<tr>
<th>Active vs passive RJP</th>
<th>Position of measurement at reference angle</th>
<th>Flexion to 120°</th>
<th>Extension to 70°</th>
<th>Extension to 50°</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEA</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Contralateral</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Control</td>
<td>.00001</td>
<td>.003</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS, not significant; RJP, reproduction of the joint position; TEA, total elbow arthroplasty.

* If P values were >0.05, then NS was indicated.

Figure 2 Results of error of passive reproduction of the joint position (EPRJP) in the operated-op elbow from total elbow arthroplasty (TEA) group, the contralateral elbow in the TEA group and the elbow in the healthy control group. P values from analysis of variance. NS, not significant.

Figure 3 Results of error of active reproduction of joint position (EARJP) in the operated-on elbow from the total elbow arthroplasty (TEA) group, the contralateral elbow in the TEA group, and the elbow in the healthy control group. P values from analysis of variance. NS, not significant.
and Ishii et al, total knee arthroplasty did not decrease upper limb in several studies. Even damaged innervation be cutaneous afferentation, which has been shown in the ability to control joint position.

certainly one of the major factors disturbing the JPS and the Extensive muscle and tendon damage during surgery is an important contributor to finger joint proprioception. Farrel joints. Articular proprioception has been found to be well understood and probably different among particular joints. Articular proprioception has been found to be an important contributor to finger joint proprioception. Farrel and Craske found that anesthetic blocking of sensation had a significant disturbance of joint position matching. Because the sensation was diminished, but not totally lost, this suggests that muscle afferents are also responsible for some residual awareness of finger position. The intra-articular injection of anesthetic to the elbow and knee did not show a significant impact on JPS in other studies. The explanation for the phenomenon could be more muscular anatomy of larger articulations, like the elbow and the knee, resulting in a more significant role of muscle spindles and tendons in neuromuscular control.

We could also argue about the role of capsulectomy in decreasing the proprioception. In studies by Barrack et al and Ishii et al, total knee arthroplasty did not decrease joint sensation. They have reported a various amount of capsulectomy in their cohorts and no muscle detachments. Such an observation had been explained by substantial extracapsular contribution to joint proprioception. We suppose that extensile muscle detachment could be the main reason for diminished passive and active control of the elbow when TEA was applied. This could have a potential effect on less aggressive surgery and planning new prosthetic designs. Such is the case for unlinked elbow replacement that does not require flexor and extensor release or ligament excision. The preservation of muscular attachments might be important for a better control of the elbow and, possibly, a better performance of patients.

There are certainly many other factors that could influence the JPS in our group of patients and control participants. Age is one of the factors that negatively affects the proprioception abilities of humans. The age range of 20 to 30 years, according to Goble et al, has the best characteristics of proprioceptive acuity, whereas populations aged 35 to 50 years and older than 70 years are progressively worse in matching joint positions. In the Kaplan et al study, healthy women aged older than 60 years had lower scores (7°) in knee positioning than teenaged girls (5°). Hurlay et al reported a decline in proprioception in lower limbs that was larger in older individuals and was correlated with decreased activities of daily living and fear of falling.

<table>
<thead>
<tr>
<th>Reference position</th>
<th>Movement mode</th>
<th>Correlation</th>
<th>Pain (VAS)</th>
<th>DASH</th>
<th>MEPS</th>
<th>Range of Flexion</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion to 110°</td>
<td>Passive</td>
<td>Spearman $\rho$</td>
<td>$-0.17$</td>
<td>$-0.13$</td>
<td>$0.21$</td>
<td>$0.01$</td>
<td>$-0.28$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$P$</td>
<td>$0.54$</td>
<td>$0.69$</td>
<td>$0.44$</td>
<td>$0.96$</td>
<td>$0.38$</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>Spearman $\rho$</td>
<td>$-0.25$</td>
<td>$-0.20$</td>
<td>$0.33$</td>
<td>$0.08$</td>
<td>$-0.33$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$P$</td>
<td>$0.05$</td>
<td>$0.25$</td>
<td>$0.01$</td>
<td>$0.74$</td>
<td>$0.79$</td>
</tr>
<tr>
<td>Extension to 70°</td>
<td>Passive</td>
<td>Spearman $\rho$</td>
<td>$-0.03$</td>
<td>$-0.07$</td>
<td>$0.18$</td>
<td>$0.21$</td>
<td>$-0.13$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$P$</td>
<td>$0.92$</td>
<td>$0.79$</td>
<td>$0.50$</td>
<td>$0.44$</td>
<td>$0.63$</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>Spearman $\rho$</td>
<td>$-0.20$</td>
<td>$-0.15$</td>
<td>$0.28$</td>
<td>$0.50$</td>
<td>$-0.32$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$P$</td>
<td>$0.39$</td>
<td>$0.12$</td>
<td>$-0.05$</td>
<td>$0.00$</td>
<td>$-0.26$</td>
</tr>
<tr>
<td>Extension to 50°</td>
<td>Passive</td>
<td>Spearman $\rho$</td>
<td>$-0.20$</td>
<td>$0.40$</td>
<td>$0.08$</td>
<td>$-0.14$</td>
<td>$0.07$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$P$</td>
<td>$0.59$</td>
<td>$0.25$</td>
<td>$0.83$</td>
<td>$0.69$</td>
<td>$0.85$</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>Spearman $\rho$</td>
<td>$-0.35$</td>
<td>$0.29$</td>
<td>$0.23$</td>
<td>$0.29$</td>
<td>$-0.28$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$P$</td>
<td>$0.54$</td>
<td>$0.41$</td>
<td>$-0.39$</td>
<td>$0.35$</td>
<td>$0.33$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pearson Cor. Coef.</td>
<td>$-0.57$</td>
<td>$0.37$</td>
<td>$-0.47$</td>
<td>$0.39$</td>
<td>$0.39$</td>
</tr>
</tbody>
</table>

*Cor. Coef.*, correlation coefficient; DASH, Disabilities of the Arm, Shoulder and Hand; MEPS, Mayo Elbow Performance Score; VAS, visual analog scale.
disabilities, slower motor functions, and poorer neuromuscular control. Age-related changes have been attributed to losses in neuromuscular control on different levels, including decreases in the number or the alteration of receptors located in the skin and in articular mechanoreceptors. There has also been a dramatic decrease in the cortical representation of motor and sensory domains.  

However, our study on elbow proprioception did not confirm age-related problems. JPS was decreased in replaced elbows compared with the healthy group and with the contralateral elbows of the same patients. Although the control group was not age-matched (significant age difference of 59 vs 26 years) we did not observe any significant difference between JPS of the contralateral (non-TEA) elbows of our patients with the healthy young group. The group of the patients, however, was not uniform for a scientifically pure comparison (age range, articular abnormalities).

Another issue is connected with osteoarthritis, which could also have an influence on the results. Koralewicz and Engh found a reduced JPS in arthritic knees compared with age-matched individuals without osteoarthritis. Patients with a unilateral osteoarthritic knee had inferior proprioception in both knees (including nonarthritic). Barrack et al showed that proprioception of the knee declines with age and that the decline is aggravated in the presence of joint degeneration. They argued the possibility of "proprioceptive neuropathy," which could contribute to joint destruction through abnormal weight bearing.

We did not measure proprioception before the operation, although such attempts were made previously. Severe arthritis of the elbow with instability made the measurement impossible, or very difficult, because of instability, a limited ROM, and discomfort. Results were compared with contralateral elbows, and results of the latter were no different than among young healthy controls. Bennell et al did not find any significant correlation between pain and disability in arthritic knees and proprioception. They questioned the functional relevance of proprioception deficits in case of joint degeneration, implying that JPS is affected by factors other than pain and that deficits in JPS are not large enough to have an effect on the disability, yet which may be joint or extremity dependent. In our study, patients who performed better after the operation (MEPS) showed better active control the flexion movement.

We also ignored limb preference in our study. Individuals in the healthy control group had similar results of all measurement sets, with no significant differences; therefore, results of dominant and nondominant elbows were combined. The main group was too small to find any reliable correlation. Influence of limb dominance still seems to be a debatable issue. Studies of the lower limb have suggested that dominance is not the factor in acuity of the knees. However, publications on the upper limb suggest a proprioceptive advantage in nonpreferred arms. Results have suggested that the dominant arm relies more on visual control, whereas the nondominant arm relies on proprioceptive information. Another explanation is that of the left arm guidance being linked to the right hemisphere, which plays an important role in proprioception. Roy et al showed a left hand advantage in thumb positioning over the right hand but no difference in arm positioning. No significant dominance-related differences of the JPS in a healthy population were detected in our previous studies on the shoulder.

For a general interpretation of proprioception, some caution is needed due to the diversity of measurement methodologies among different studies. We used a system that combines the stable frame for elbow motion in a passive mode and stable arm support for active motion. This was created to exclude the influence of any postural disturbances on our results. Unstable or unsupported elbow motion may reflect the information not only from elbow receptors but may also activate the shoulder muscles. Using the same limb for presentation of position and reproduction (ipsilateral matching) in our study relies not only on a sensory-motor system but also on the patient’s ability to memorize the reference angle. JPS in our system does not exclude some memory or cognitive deficits. To our best knowledge none of our patients was diagnosed with a neurologic problem. Alternative contralateral matching (when the individual reproduces the reference angle of contralateral joint without the need of memorizing it) would exclude the possibility of bilateral comparisons.

Passive and active joint matching were both used in our experiment. This was performed to reflect both afferent (passive mode) and a combination of both afferent and efferent pathways (active mode). No significant differences were seen among the patients. However, the control group revealed better angle matching in the active mode for flexion and for passive extension to 70°.

Only a few studies on elbow proprioception in the literature have used different systems of measurement. Our system combined the stable frame and motorized passive movement of the Biodex system and a high-accuracy electronic goniometer (to 0.1°) with precise matching control of the Propriometer. Khabie et al used the same frame for elbow measurement and used the values from the Biodex system. The average inaccuracy (error) angle was similar to our control group (~3.3°). Another experiment by Zia et al used the electric goniometer to measure elbow angles in patients with Parkinson disease. The patient’s arm and elbows were not supported, and limb alignment was stabilized by the patient’s own musculature. Their study showed that the normal control group revealed a very high level of acuity in the reproduction of JPS, reaching an average of 0.5°. This is far better than in our report, and also proven by others. That has been explained in the form of an angle visual presentation and narrow test angles (90°-108°).

Juul-Kristensen et al studied elbow proprioception in patients with lateral epicondylitis and found the JPS was higher for patients with lateral epicondylitis (8.2°)
compared with healthy controls (5.6°). Hattori et al\textsuperscript{18} also explored JPS in patients with complete brachial plexus lesions whose active elbow flexion had been restored with muscle transfer. They found an error of JPS in operated patients of 5° compared with 4° for the healthy control group.

Most of the reports do not include the accuracy of the measurement system. The exception is a study by Tripp et al,\textsuperscript{38} who used an electromagnetic tracking device with an accuracy of 0.5° to evaluate the influence of vibration training on elbow proprioception. The distal arm was supported against some support, but the actively reproduced angle of 90° was not guided by any apparatus. The measured error ranged from 5.4° to 7° and was significantly decreased by vibration training from 4.7° to 6.3°. However, whether the improvement was was due to an improved efficiency of transmission, processing, or integration of afferent or efferent signals was not clear.

These few studies show that elbow proprioception is definitely interesting subject. JPS in the elbow joint might be affected by multiple conditions. In our study, JPS was inferior after TEA. We could argue that the major reason could be operative injury to muscle/tendon units due to exposure. Further investigations are necessary, possibly including JPS evaluation after other surgical procedures, less extensile approaches, or a different rehabilitation protocol.

### Conclusion

Proprioception in elbows that undergo total arthroplasty is significantly inferior compared with the patient’s contralateral side and with a healthy control group. A possible explanation is extensive surgery causing damage to the tissues that are the main sources of proprioceptive information (skin, muscle, tendon, capsule, and ligaments). The role of proprioception in patients’ disability and elbow stability after TEA is unknown. However, our study suggests caution when performing the extensile approach, preservation of muscle attachment when possible, and avoidance of large elevation of skin flaps from over the muscle. These findings could also be included in designing new prosthetic designs using a less invasive technique of implantation.

### Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

### References


