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INVESTIGATION OF THE ACTIVE JOINT POSITION SENSE FOLLOWING ROTATOR CUFF REPAIR SURGERY

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ABSTRACT

Purpose: Decreased active joint position sense has been documented in rotator cuff tears. However, there is limited information regarding whether proprioceptive impairments could be recovered after arthroscopic rotator cuff repair surgery. This study aimed to evaluate the shoulder active joint position sense following an arthroscopic rotator cuff repair and compare the differences between the non-operated contralateral sides of the patients and healthy controls.
Methods: Fifteen patients with arthroscopic rotator cuff repair and fifteen healthy controls were included. Shoulder active joint position sense was assessed using the Laser-pointer-assisted Angle Reproduction Test at 90° of the forward flexion and abduction positions at the post-operative 3rd month in patients with arthroscopic rotator cuff repair (both sides) and healthy controls (dominant side). Shoulder active range of movements and pain intensity were also recorded.
Results: Similar active shoulder joint position sense was found in the patients on both sides and the dominant side of the healthy controls at 90° of forward flexion ($p>0.05$), yet it was significantly worse in the patients' operated sides than in the non-operated sides at 90° of abduction ($p = 0.034$). Active range of movements was significantly worse in the patients' operated sides than in the non-operated sides and the healthy controls' dominant sides ($p<0.05$). Pain intensity was not correlated with active joint position sense ($p>0.05$).
Conclusion: This study reveals that active joint position sense may be restored in the third month following arthroscopic rotator cuff repair surgery compared to the non-operated contralateral sides of the patients and dominant sides of the healthy controls.
Keywords: proprioception, active joint position sense, rotator cuff, repair

ÖZET

Amaç: Rotator kılıf yırtığı olan hastalarda aktif eklem pozisyonu hissinin azaldığı bilinmektedir. Ancak artroskopik rotator kılıf tamiri cerrahisinden sonra propriyoseptif defisitin düzelip düzelmeyeceğine ilişkin yeterli bilgi bulunmamaktadır. Bu çalışmanın amacı, artroskopik rotator kılıf tamiri cerrahisi sonrası omuz aktif eklem pozisyonu hissinin değerlendirilmesi ve hastaların cerrahi uygulanmayan karşı tarafları ile sağlıklı kontroller arasındaki farkların karşılaştırılmasıydı.
Yöntemler: Artroskopik rotator kılıf tamiri cerrahisi uygulanan 15 hasta ve 15 sağlıklı kontrol çalışmaya dahil edildi. Ameliyat sonrası üçüncü ayda, artroskopik rotator kılıf tamiri ameliyatı olan hastalarda (her iki taraf) ve sağlıklı kontrollerde (dominant taraf) omuz 90° fleksiyon ve abduksiyon pozisyonlarında Lazer İşaretçi Destekli Açı Tekrarlama Testi kullanılarak omuz aktif eklem pozisyonu hissi değerlendirildi. Hastaların omuz aktif hareket açıklığı ve ağrı şiddetleri de kaydedildi.
Bulgular: Hastaların cerrahi uygulanan ve cerrahi uygulanmayan karşı omuzları ile sağlıklı kontrollerin dominant taraflarında aktif omuz eklem pozisyonu hissi değerleri omuz 90° fleksiyon pozisyonunda benzerdi ($p>0,05$). Ancak hastaların cerrahi uygulanan omuz cerrahi olmayan karşı omuza göre 90° abduksiyonda ölçülen aktif eklem pozisyonu hissi değerleri anlamlı derecede kötüydü ($p = 0,034$). Hastaların cerrahi uygulanan omuz eklem hareket açıklığı değerleri cerrahi uygulanmayan karşı taraf ($p<0,05$) ve sağlıklı kontrollerin dominant taraflarına göre anlamlı derecede daha kötüydü ($p<0,05$). Ancak, ağrı şiddeti ile aktif eklem pozisyonu hissi değerleri ilişkili bulunmadı (90° fleksiyonda: $r = -0,258$; $p = 0,354$ ve 90° abduksiyonda: $r = -0,142$; $p = 0,629$).
Sonuç: Bu çalışma, hastaların ameliyat edilmeyen kontralateral tarafları ve sağlıklı kontrollerin dominant tarafları ile karşılaştırıldığında aktif eklem pozisyonu hissinin artroskopik rotator kılıf tamiri cerrahisini takip eden üçüncü ayda restore edilebildiğini ortaya koymaktadır.
Anahtar Kelimeler: propriyosepsiyon, aktif eklem pozisyon hissi, rotator kılıf, tamir

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INTRODUCTION

Rotator cuff-related shoulder problems are the most common cause of shoulder pain and dysfunction in the general population (1-3). With aging, the severity of the degenerative condition may result, ranging from subacromial pain syndrome to full-thickness massive rotator cuff tears (3). Rotator cuff tears are associated with pain, functional impairment, and disability in daily living activities (3). Although conservative management is considered a first-line treatment option, surgical repair is often preferred depending on clinical and morphological factors, including tear size and thickness, the potential for tendon healing, and patient risk factors (3). Currently, the standard surgical approach is arthroscopic rotator cuff repair (ARCR), followed by postoperative rehabilitation (4-7). The important goal of postoperative rehabilitation following the ARCR is to restore neuromuscular control of the surrounding muscles, the shoulder range of movements, and the proprioceptive sense (4, 5, 7-9).

Proprioception is defined as a sense of the relative position of one's body parts and movement (8, 10). The joint position sense (JPS) is one of the elements of proprioception, defining the ability to sense and feel the position and movement of the joint (active or passive) in space without visual control (10, 11). The JPS is assessed using active or passive joint replication, while the movement sense is evaluated by measuring the threshold for active motion detection (12). Balke et al. examined the reliability of shoulder proprioception using the active JPS test named the laser-pointer assisted angle reproduction test (LP-ART) and obtained excellent results (11, 13).

Muscular and ligamentous injuries in the shoulder joint might damage the proprioceptive receptors in those structures, leading to proprioception deficits and, thereby, a secondary injury (14, 15). Besides, any proprioceptive deficit could compromise neuromuscular control and affect shoulder stability, developing a vicious cycle that can worsen treatment outcomes (14). Therefore, assessing and monitoring proprioceptive sense could affect the treatment outcomes of injured shoulders and aid in developing preventive rehabilitation strategies for subsequent injuries.

Previous studies have well-documented impaired proprioceptive sense in patients with rotator cuff-related shoulder problems (15-18). Furthermore, they have revealed that the loss of the JPS is related to rotator cuff tear severity, and two or more tendon involvements or massive rotator cuff tears could cause higher proprioceptive impairments (15, 17). However, to date, no study has evaluated the JPS following ARCR surgery and post-operative rehabilitation. Little is known regarding whether proprioceptive impairments could be recovered post-operatively after ARCR surgery. To elucidate this unresolved question, we aimed to assess shoulder proprioceptive deficit through the evaluation of JPS using LP-ART in a group of patients who underwent an ARCR surgery and compared the findings with those of non-operated sides and healthy controls. We hypothesized that active shoulder JPS would improve following ARCR surgery and post-operative rehabilitation.

METHODS

Study Design

This study used a cross-sectional, case-control study design; each patient's non-operated limb was assessed for their own internal control, and the dominant limbs of the healthy volunteers were assessed for external control. Prior to study participation, participants were informed of the nature of the study and they were signed a consent form. The University Institutional Review Board approved the study protocol (GO16/75-14).

Participants

This study was conducted on 15 patients, aged 45 to 70 years, following ARCR surgery and on 15 sex-matched healthy controls. Patients were recruited from our physiotherapy clinic (who underwent ARCR surgery in Hacettepe University Orthopedics and Traumatology Department), and healthy controls were recruited from the general population (via social media announcements). Patients with the following conditions were included: (a) aged 45 to 70 years, had a unilateral arthroscopic repair of a rotator

cuff tear measuring small (<1 cm) and/or medium (1-3 cm) (19), which was caused by a degenerative process, (b) had not had a preoperative shoulder stiffness (a passive forward elevation < 100° or external rotation < 30°), (c) regained at least seventy-five percent shoulder elevation eight weeks after surgery, (d) able to reach at least third months after the operation, and (e) free from acute shoulder pain. The exclusion criteria were (a) previous fracture of proximal humerus or shoulder dislocation, (b) bilateral cases, (c) full-thickness and/or massive rotator cuff tear/repair, (d) recurrence or re-tear, (e) radiographic signs of arthritis, and (f) follow-up < three months. Patients were also excluded if they had thoracic hyper kyphosis and any rheumatologic, systemic, or neurologic disorders or any neuromusculoskeletal disorder (including cervical radiculopathy).

Additionally, fifteen healthy participants (hand-dominance and sex-matched) were included as a control group (CG). The CG was asymptomatic and was free from any shoulder pathology. To assess rotator cuff tendon status, the CG was subjected to a physical examination of the anterior and posterosuperior rotator cuff tendons. If one or more clinical tests were positive, the participant was excluded from the CG since they could have an asymptomatic rotator cuff tear.

Procedure

The procedure consisted of two stages. In the first stage, ARCR surgery was performed for all eligible candidates, and patients received a post-operative rehabilitation program over three months. In the second stage, active shoulder JPS and pain intensity (for the patients) were recorded.

Surgical Procedure and Post-operative Rehabilitation

The surgical procedure was performed by the same orthopedic surgeon with the patient under general anesthesia and in the beach chair position. First, a standard lateral portal was placed for viewing. Soft tissue was extracted from the lower surface of the acromion, and the coracoacromial ligament was released subperiosteally and debrided. If necessary, an acromioplasty was performed. The edges of the rotator cuff were debrided, and the mobility of the tear was ensured—a double-row fixation with a trans osseous equivalent technique for all repairs.

Postoperatively, patients received a post-operative rehabilitation program over a 3-month duration. In the first week, a standardized arm sling was advised for all patients for the first six weeks, and instructions were given (not to elevate their shoulders actively and how to perform active wrist exercises). In the second week after ARCR, all patients were initiated into the same standardized rehabilitation program recommended by Thigpen et al. (6, 9, 20). The rehabilitation program included passive shoulder range of movement (ROM) exercises, scapular retraction, and active cervical ROM exercises. Then, patients progressed into active-assistive, active, and strengthening exercises during the rehabilitation program (6, 9). The rehabilitation program primarily aimed to restore shoulder ROM, rotator cuff strength, and scapular control (6, 9). If required, manual therapy techniques were applied. Patients were also advised a home exercise program and instructed to perform the exercise daily. Once patients reached the third month following the operation, outcomes were recorded.

Outcome Measures

Demographic characteristics of the participants (i.e., age, sex, symptom duration till surgery, operated side, and dominant side) were recorded at baseline. Then, the primary outcome was the laser-pointer assisted angle reproduction test (LP-ART) for active shoulder joint position sense, and the secondary outcomes were the shoulder ROM measurements and the Visual Analogue Scale (VAS) for pain severity.

Active Shoulder Joint Position Sense was assessed using the Laser-pointer-assisted Angle Reproduction Test (LP-ART), also known as the active shoulder angle repetition test developed by Balke et al. (11). The inter-rater (ICC = 0.86) and intra-rater (ICC = 0.78) reliabilities of the LP-ART were reported to be good to excellent in the shoulder joint (13).

Prior to testing, each participant was informed of the procedure and familiarized with the testing procedure. The participants were asked to wear a training top (female) or

remain bare-chested (male) to reduce external skin stimulation. During testing, women with long hair were instructed to make their hair a ponytail to prevent glenohumeral joint tactile feedback. To standardize positioning, participants stood upright with their feet positioned shoulder-width apart, upper limbs at their sides, elbows extended, and forearms in a neutral position. Participants were instructed to keep their neutral trunk posture and head facing forward. A light laser pointer was attached to the lateral side of the arm by using a wristband just above the lateral epicondyle to eliminate the possible involvement of the elbow joint during the repositioning task.

Testing consisted of two phases: training and actual testing procedure. During the training, participants were asked to stand in front of a vertical (240 cm) scale attached to the wall in front of them. They were then asked to perform active shoulder forward flexion in the sagittal plane until they reached the target position (90° of flexion) with open eyes. The target shoulder position was checked using a standard goniometer. In this position, the location of the laser dot on the scale was considered a point "0" for the subsequent measurements. While keeping the arm at 90° of forward flexion, the participants were positioned so that the vertical distance from the shoulder joint (center of rotation) to point "0" on the scale was equal to the length of the arm plus 10 cm. After each arm movement, the assessor recorded the arm position as indicated by the laser dot on the scale. Then, the participants were instructed to maintain the testing posture with their eyes open and heads directed forward toward the center of the target. They were asked to perform active forward flexion in the sagittal plane with open eyes until they reached the target position (90° of shoulder elevation in the sagittal plane) and instructed to memorize this joint position. Patients were asked to reach the target position with closed eyes for familiarization. When patients felt they had reached the target position, they were instructed to stop their arms. After acquiring position security, the upper limb returned to its side and started the actual testing without visual feedback.

During the actual testing, the participants closed their eyes and wore a blindfold. The assessor provided some orientation to maintain the head directed forward and the wrist in neutral. Then, testing was conducted; once participants declared that they reached the target position, the assessor noted the coordinates X and Y of the joint positioning, representing the angular deviation from the target position. All participants performed three trials for each shoulder, both in active forward flexion in the sagittal plane and active abduction in the frontal plane, with an interval of 5 seconds. Mean values were used for data analysis.

For the experimental group, all patients had right shoulder dominance, and the dominant sides had an ARCR surgery. They were tested on both operated and non-operated shoulders. For the control group, all subjects had right shoulder dominance, and only the dominant shoulder was evaluated.

Each participant followed the same standardized procedure, and the same examiner performed all testing procedures to reduce inter-rater variability. Additionally, to minimize the learning effect, a randomization list was generated that shows the measurement order for all participants by using a computer-based allocation program (www.randomizer.org). Three blinded assessors performed the testing independently. The first assessor performed the LP-ART, blinded to calculation and data entry/analysis but not to the patients' symptomatic side. The second assessor calculated deviations from the coordinates X and Y and recorded them in millimeters. The third assessor was responsible for the data entry and the calculations of the angular deviations.

Besides, we calculated the intra-session reliability of the LP-ART. Three trials of the LP-ART were used to determine the intra-session reliability of the first assessor at each shoulder position.

Shoulder Range of Movement was assessed using a standard goniometer. Measurements were taken when participants were in a supine lying position. Shoulder flexion, abduction, and external (ER) & internal rotation (IR) active range of movements were recorded in degrees. Besides, active total elevation was recorded while the patients were standing in the sagittal plane (21).

Pain Intensity (during shoulder elevation) was measured using a 100-mm VAS that consisted of a 100-mm straight line with endpoints defining the pain intensity (22). Patients were asked to mark their pain level that corresponds to their pain intensity on the line between "0 = no pain" and "100 = the worst pain imaginable" (MCID = 14 millimeters) (23).

Sample Size Calculation

The sample size was calculated using the G*Power for Mac (Version 3.1.9.6; Universitat Dusseldorf, Germany) to detect the smallest significant difference in joint position sense. The sample size was estimated as follows: a) smallest significant difference of 6 degrees on the LP-ART, b) assuming an SD of 2.9 degrees, c) a significance level of 5%, d) power of 95%, e) a 20% drop-out (24, 25). After all, the required sample size was 15 participants for each analysis (26, 27).

Data Analysis and Statistical Analysis

Prior to data analyses, the absolute angular deviation of the LP-ART measurement (the absolute difference in degrees between the target position and the corresponding position of the laser dot on the scale) was calculated in the Excel software (Microsoft Corporation, 2019) using the following Pythagorean theorem according to Balke et al. 2011 (11).

$C = \sqrt{x^2+y^2}$

The "c" value was calculated through the horizontal (x) and vertical (y) distances of the deviation of the laser dot on the scale from the target position, and the "c" value was converted from centimeter to the absolute angular deviation in degrees using the following formula in the Excel software (2019), which 100 is the distance from the target (1 meter):

$\alpha = tan^{-1}(c/100)$

As for the LP-ART, intraclass correlation coefficients ($ICC_{2,1}$) with corresponding 95% confidence intervals (CI) were used to interpret the intra-session reliability of the LP-ART (28). The error of LP-ART measurement was calculated using the standard error of measurement (SEM) and minimal detectable change (MDC) with 95% CIs ($MDC_{95\%}$):

$SEM = (SD \times \sqrt{1-ICC})$, $MDC_{95\%} = SEM \times 1.96 \times \sqrt{2}$ (29).

The Kolmogorov-Smirnov test was used to assess the normality and homogeneity of the data. After log transformation, the paired *t*-test was used to compare the mean difference between the operated and non-operated sides of the ARCR patients, and the independent samples t-test was used to compare the operated sides of the ARCR patients and the dominant sides of the CG. The Spearman Rank test was then used to analyze the relationship between absolute angular deviation and pain intensity as the non-normal residual distribution. The correlation was defined to be "good" (if ≥ 75% of the hypotheses could be confirmed), "moderate" (in case of 50–75% confirmation), or "low" (<50% of confirmation) (30). A significance level of 0.05 was set. Statistical analysis was performed using the SPSS version 22 (SPSS Inc., Chicago, IL, USA).

RESULTS

Between August 2021 and July 2023, twenty-one potential candidates were assessed for eligibility. However, six patients were excluded from the study since their passive forward elevation was less than 100°. As planned, 15 patients with ARCR surgery (7 male; 8 female; mean age: 51.4±8.2 yrs., BMI: 26.5±2.4 kg/m^2, mean symptom duration: 4.2±1.2 yrs) and 15 asymptomatic sex-matched controls (7 male; 8 female; mean age: 38.6±5.9 yrs., BMI: 25.5±2.6 kg/m^2) were enrolled.

For active joint position sense (absolute error), there was no significant difference found between the operated sides and non-operated sides of the patients following ARCR surgery at three months at 90° of forward flexion ($p>0.05$). However, the active shoulder position sense was significantly worse in the operated sides of the patients than in the non-operated sides at 90° of abduction *($p = 0.034$, mean difference = 3.6°)*. When comparing the operated side of the ARCR patients with the dominant side of the CG at 90° of forward flexion and 90° of abduction, no significant difference was found ($p>0.05$). Detailed results of active JPS measurements are presented in Table 1.

Table 1. Differences in joint position sense (absolute error) between the ARCR surgery patients (operated and non-operated sides) and CG at 90° of forward flexion and 90° of abduction, and mean differences with 95% confidence intervals between groups according to LP-ART

	Patients with ARCR		Dominant Side of the CG	Within Group Change			Between-Group Change		
	operated side	non-operated side		mean differences	t	p value	mean differences	t	p value
90° of Forward Flexion	11.7 (8.6)	10.2 (5.2)	12.4 (8.9)	1.5 (-3.6 to 6.6)	0.612	0.550[a]	-0.8 (-7.3 to 5.8)	-0.237	0.814[b]
90° of Abduction	10.8 (8.4)	7.2 (4.8)	13.5 (6.6)	**3.6 (0.3 to 6.9)**	**2.372**	**0.034[a]**	-2.7 (-8.4 to 3.1)	-0.953	0.349[b]

[a]p< 0.05; paired samples t-test; [b]p<0.05; independent samples t-test
Note: values are indicated as mean (standard deviation)
Abbreviations: ARCR= arthroscopic rotator cuff repair; CG= control group

Table 2. Differences in shoulder range of movements between the ARCR surgery patients (operated and non-operated sides) and CG, and mean differences with 95% confidence intervals between groups

	Patients with ARCR		Dominant Side of the CG	Within Group Change			Between-Group Change		
	operated side	non-operated side		mean differences	t	p value	mean differences	t	p value
Forward flexion	158.9 (14.9)	180	180	**-21.1 (-29.3 to -12.8)**	**-5.473**	**<0.001[a]**	**-21.1 (-28.9 to -13.2)**	**-5.473**	**<0.001[b]**
Abduction	149.6 (22.1)	180	180	**-30.4 (-43.1 to -17.7)**	**-5.137**	**<0.001[a]**	**-30.4 (-42.5 to -18.3)**	**-5.137**	**<0.001[b]**
ER	63.5 (17.8)	91.7 (6.5)	90	**-28.1 (-38.3 to -18)**	**-5.960**	**<0.001[a]**	**-26.5 (-36.3 to -16.6)**	**-5.763**	**<0.001[b]**
IR	73.3 (14.2)	87.7 (4.9)	88.4 (1.2)	**-14.3 (-22.2 to -6.5)**	**-3.916**	**0.001[a]**	**-15.1 (-24.2 to -9.2)**	**-5.473**	**<0.001[b]**

[a]p< 0.05; paired samples t-test; [b]p<0.05; independent samples t-test
Note: values are indicated as mean (standard deviation)
Abbreviations: ARCR= arthroscopic rotator cuff repair; CG= control group; ER=external rotation; IR= internal rotation

Additionally, intra-session reliability of the LP-ART revealed excellent reliability and acceptable measurement error at 90° of forward flexion ($ICC_{2,3}$ *= 0.90, SEM = 2.7°,* $MDC_{95\%}$ *= 5.3°*) and 90° of abduction positions ($ICC_{2,3}$ *= 0.88, SEM = 3.06°,* $MDC_{95\%}$ *= 6.06°).*

Shoulder range of movements (forward flexion, abduction, ER, and IR) was significantly worse in the operated sides of the ARCR patients when compared to the non-operated sides of the patients and the dominant side of the CG (*p<0.05*; Table 2).

The mean pain intensity of the patients was 0.9±1.8 (0-6). No significant relationship was found between joint position sense (absolute error) and pain intensity at 90° of forward flexion (*r = -0.258; p = 0.354*) and 90° of abduction positions (*r = -0.142; p = 0.629*).

DISCUSSION

This study aimed to investigate the active JPS using the LP-ART in patients who underwent ARCR surgery and to compare the proprioceptive deficit with the non-operated side of the patients (internal control) and healthy controls (external control). The findings of this study revealed that patients (operated and non-operated sides;) and healthy controls displayed similar active JPS in the third month at 90° of forward flexion. Besides, similar active JPS was observed between the operated sides of the patients and healthy controls at 90° of shoulder abduction. However, at 90° of shoulder abduction position, active JPS was lower on the operated sides compared to the non-operated sides of the patients in the postoperative third month. Our study further revealed that the shoulder range of movements was not fully restored in the first three months following the ARCR

surgery, and pain intensity during shoulder movements was not related to active JPS.

To our knowledge, this is the first study comparing the active JPS using the LP-ART in patients who underwent ARCR surgery. We included patients who had small (<1 cm) and/or medium (1-3 cm) sized rotator cuff tears before the surgery since the severity of the rotator cuff tear could cause greater proprioceptive impairment (19). Our main reasoning was that if two or three tendons (massive tears) are involved, a greater peripheral receptor involvement could lead to greater damage to the peripheral proprioception. Furthermore, the greater muscle spindles and golgi tendon involvement could lead to greater proprioceptive impairments, developing shoulder instabilities that may have affected our findings. Following the surgical procedure, we included all patients in a three-month standardized rehabilitation program. Previous studies have demonstrated an impaired proprioceptive sense in shoulder instability, shoulder joint degeneration, adhesive capsulitis, and rotator cuff pathologies (17, 31, 32). Furthermore, they reported that proprioceptive sense could be restored following the total reverse shoulder arthroplasty and shoulder stabilization procedures (33, 34). In addition to previous findings, this study fills an important gap in the literature regarding how impaired proprioceptive sense changes when the rotator cuff tear is surgically repaired. The current findings separately showed that active JPS is restored three months after the ARCR surgery.

There is no indicative value in the literature for describing the pathological proprioceptive deficit using the LP-ART. Therefore, we could not easily say whether our patients have shown pathological active JPS or not. Yet, we calculated our clinical meaningfulness, calculating MDCs with 95% confidence intervals. MDCs are often used to interpret the size of between-group effects (which can be detected objectively as true change outside of the measurement error) (35). In our study, the differences in LP-ART values were interpreted in relation to the MDCs. Although the operated sides of the patients demonstrated statistically greater proprioceptive deficit (absolute angular deviation) compared to non-dominant sides (mean difference = 3.6°) at 90° of shoulder abduction, extremity differences and the group differences in both forward flexion ($MDC_{95\%}$ = 5.3°) and abduction ($MDC_{95\%}$ = 6.06°) were lower than the calculated MDCs values. Therefore, we could say that the within-the-group and between-group differences did not demonstrate a clinically meaningful change in the third-month evaluation following the ARCR surgery. Furthermore, there is no standardization for the fixation of the laser pointer device in the original testing procedure (11, 13). In our study, we fixed the laser pointer just above the elbow to prevent accidental wrist movements that could interrupt the laser beam or cause unexpected deviation.

In our study, we measured active JPS at 90° of shoulder elevation in the coronal and sagittal planes. Testing was repeated three times for shoulder flexion and abduction so that 12 points were recorded for each patient. The original testing method uses three reproduction angles (55°, 90°, and 125°), and 36 points are recorded for each participant. Since our patients were in the early period following the surgical repair of the rotator cuff tear, we selected only 90° of forward flexion and abduction. The main reasons can be explained as follows. The first reason is to prevent muscular fatigue (12, 16). The second reason was to avoid the possible learning effects (12, 16). The final and primary reason was the different activation patterns of the mechanoreceptors during the active shoulder elevation task (36). Especially in the mid-range (around 90° of elevation), musculotendinous mechanoreceptors are more predominant than capsuloligamentous mechanoreceptors during active repositioning tasks (13, 36). Since we desired to investigate musculotendinous mechanoreceptors (muscle spindles and golgi tendon) rather than capsuloligamentous mechanoreceptors, we preferred 90° of forward flexion and abduction positions. Our tentative finding suggests that researchers or clinicians should choose the mid-range shoulder elevation position if they desire to investigate rotator cuff-related active JPS. Nonetheless, future studies are needed to interpret whether active JPS differs at low-, mid-, and high-range active shoulder elevation tasks.

In this study, it is important to note that pain intensity was not found to be associated with the LP-ART. Our results are

in line with the recent literature findings that demonstrate shoulder proprioception is not influenced by patient symptoms (17, 37, 38). Impairments of the proprioceptive sense may be more related to impaired musculotendinous and capsuloligamentous proprioceptive receptors, such as the rotator cuff tear severity rather than symptom severity. One study stated that shoulder proprioception impairment was higher in patients with massive RCTs whose pain intensity was significantly lower than that of participants with less severe disease (17). Similarly, another study reported that experimentally induced subacromial pain did not affect shoulder proprioception (39). In light of the findings above, we could speculate that rotator cuff pathologies are often considered chronic lesions that could cause proprioceptive deficits even if they could be asymptomatic for many years.

Limitations: This study had limitations. First, we assessed the active JPS three months following the postoperative period, yet we did not have a chance to evaluate the patients preoperatively. Therefore, we could not compare the patients' proprioceptive improvements or deficits with the preoperative data. Second, our control group was younger than the patients with ARCR surgery. Still, as outlined in the methodology, we considered the opposite shoulder as an internal control of the ARCR surgery group to be an appropriate age-matched comparison. Therefore, the healthy volunteers considered an external control group were selected to represent the normal JPS free from shoulder pain. Then, we included our patients in a standardized post-operative rehabilitation program, not a specific proprioceptive exercise program. Therefore, we cannot comment on whether proprioceptive-specific rehabilitation programs could provide better results. Finally, patients had a unilateral arthroscopic repair of a small and medium rotator cuff tear size caused by a degenerative process. Therefore, our result was not generalized to the patients with massive rotator cuff repair surgery.

CONCLUSION

Our study revealed that shoulders following ARCR surgery demonstrated a similar joint position sense when compared to the non-operated contralateral shoulders of the patients and were also similar to the healthy control group. Our study further revealed that pain intensity was not correlated with active JPS of the operated shoulder. We believe the improved proprioceptive sense was due to enhanced shoulder ROM, functionality, and biomechanics provided by the rotator cuff repair surgery and post-operative rehabilitation program. Further studies will be needed to examine the recovery of proprioception following both tendon repair and the proprioceptive-specific rehabilitation protocol.

Researcher Contribution: Substantial contributions to the conception or design of the work or the acquisition, analysis, or interpretation of data for the work (LE, ID). Drafting the work or reviewing it critically for important intellectual content (LE, EA, ID).

Final approval of the version to be published (LE, EA, ID)

Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved (LE, EA, ID)

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