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ORIGINAL RESEARCH

Effects of lower extremity physical activity on shoulder biomechanics and functional recovery in the early phase after arthroscopic rotator cuff repair in male patients: a retrospective study

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Abstract

Surgeons widely use arthroscopic rotator cuff repair (ARCR) to restore biomechanics and function in patients with rotator cuff tears. However, patients show severe pain early after ARCR, and their physical activity level decreases sharply. This study aimed to determine the effect of lower extremity physical activity on shoulder pain, biomechanics, and functional recovery in the early phase after ARCR. This retrospective study included 103 male patients according to the inclusion criteria. We classified subjects into high physical activity (HPA, n = 49) and low physical activity (LPA, n = 54) groups according to the classification criteria. For analysis, we measured the visual analog scale (VAS) score, range of motion (ROM), American Shoulder and Elbow Surgeons (ASES) score, and grip strength preoperatively and six weeks postoperatively. In comparing the HPA and LPA groups at six weeks postoperatively, the VAS score was significantly lower in the HPA group ($p < 0.001$). The ROM of forward flexion ($p = 0.001$), abduction ($p = 0.005$), and external rotation ($p = 0.001$) of the shoulder was also significantly greater in the HPA group. In particular, the ASES score ($p < 0.001$) and grip strength ($p < 0.001$) showed significant improvement only in the HPA group. Patients with higher levels of physical activity after ARCR showed lower subjective pain and faster biomechanical and functional recovery than those with lower levels of physical activity. Therefore, even if the involved shoulder has restrictions during the early phase after ARCR, it is vital to actively recommend physical activity such as walking, stationary cycling, and climbing stairs using the lower extremities.

Keywords

Rotator cuff repair; Physical activity; Shoulder pain; Range of motion; Functional recovery; Grip strength

1. Introduction

Globally, rotator cuff tear (RCT) prevalence is increasing in various age groups [1]. The reported prevalence of RCTs is between four to 32% of the total population, and the incidence increases with age [2]. Typical symptoms of RCTs are shoulder pain, limited range of motion (ROM), and decreased muscle strength. These serious symptoms limit the patient's basic activities of daily living (ADL) [3]. Therefore, surgeons widely use rotator cuff repair to relieve pain and restore shoulder biomechanics and function in symptomatic RCTs [4]. The purpose of surgical repair for RCTs is to restore the anatomical structure by repositioning the torn tendon to the greater tuberosity of the humerus [5]. In particular, since arthroscopic rotator cuff repair uses a minimally invasive technique, it is recently considered a standard method because it has the advantage of early recovery of joint ROM along with strong fixation [6].

However, although ARCR is a minimally invasive procedure, many patients still complain of significant pain immediately after surgery [7]. Often, patients who complain of severe pain in the early phase after ARCR require high-dose analgesics, which increases the risk of side effects for complications. These side effects include hypoxia, respiratory depression, hypotension, confusion, and dizziness [8]. In addition, these side effects could delay the patient's return to ADL and may negatively affect the healing of the repaired tendon [9]. Therefore, we need additional research on safe and effective interventions for pain relief to minimize the side effects caused by analgesic abuse and to achieve a successful postoperative outcome.

Many methods for effective pain control have been studied [10]. Among them, several authors have reported that exercise and physical activity are effective interventions that reduce pain and promote the healing of damaged tissues [11–13]. For example, Naugle *et al*. [11] reported that the pain threshold for induced upper limb pain increased in participants who performed stationary cycling through an experiment. This effect was proportional to the exercise intensity in a positive direction. In addition, Mork *et al*. [12] investigated the association between physical activity and chronic pain through a longitudinal study. They reported that individuals who reported lower physical activity levels had an increased risk of chronic pain. Further, Bring *et al*. [13] found that physical activity improves the healing of damaged tendons and affects neuroplasticity, and reported the peripheral nervous system can mediate these effects to distant sites. This evidence suggests that physical activity may be necessary for pain control and biomechanical and functional recovery after ARCR. However, patients use a shoulder abductor brace to immobilize the glenohumeral (GH) joint for four to six weeks immediately after ARCR [14]. During this period, as the use of the upper extremities is restricted, patients may experience significant difficulties in ADL. In addition, their physical activity level may decrease rapidly due to fear of activity and lack of awareness of the need for physical activity. This lack of physical activity, which appears early after ARCR, may delay pain relief and functional recovery. It may also delay the return to ADL or work. Therefore, patients need interventions that can increase the physical activity level in the early phase when the upper extremities shoulder immobilization restricts activities. In this regard, physical activity using the lower extremities, which are not involved with the surgical site, can be an effective alternative. Previous studies have reported that exercise using a distant uninvolved limb can be an effective intervention for relieving pain in the involved limb, even if the exercise is not directly performed using the painful involved limb [15, 16].

However, researchers have not yet addressed the effect of lower extremity physical activity on the postoperative outcome in patients who have undergone ARCR as a major research topic, and we know little about it. Therefore, we investigated the effects of physical activity using the lower extremities on shoulder pain, biomechanics, and functional recovery in the early phase after ARCR. To the best of our knowledge, this is the first retrospective study to investigate the effects of lower extremity physical activity by analyzing clinical data of patients who underwent ARCR.

2. Materials and methods

2.1 Selection and classification of subjects

Many previous studies have reported sex as a predictor influencing clinical outcomes after ARCR [17, 18]. In particular, considering that sex differences between males and females significantly affect postoperative pain and biomechanics related to shoulder ROM, this study limited the subjects to male patients to exclude confounding factors [17].

From February 2019 to January 2021, 314 patients underwent ARCR performed by the same orthopedic surgeon. Considering the pathological and psychosocial factors that may affect the postoperative outcome, we used the following exclusion criteria: female patients, patients with massive or small tears, patients with subscapularis tears, patients undergoing revision ARCR for retear, patients with other concomitant surgeries on the same shoulder, and patients with workers' compensation claims. We evaluated tear size based on DeOrio's and Cofield's classification [19]. As a result, we excluded 211 out of 314 patients, leaving 103 male patients in this retrospective study (Fig. 1). All subjects included in this study underwent subacromial decompression and ARCR using the suture bridge technique. Subacromial decompression is a procedure that increases the height of the subacromial space to relieve impingement on the rotator cuff tendon [20]. After subacromial decompression, the surgeon performed a suture bridge technique using a SwiveLock suture anchor (Arthrex, Naples, FL, USA) to reattach the torn rotator cuff tendon onto the bone (Fig. 2).

All subjects completed an International Physical Activity Questionnaire (IPAQ) every week until six weeks after surgery to measure the metabolic equivalent of task (MET). The IPAQ, which is reliable and valid in many studies, is a physical activity measurement tool consisting of seven questions that evaluate the frequency and time spent on vigorous physical activity, moderate physical activity, walking activity, and inactivity in the past seven days [21]. In this study, we investigated only physical activities using the lower extremities, such as walking, stair climbing, jogging, and stationary cycling, considering the restrictions on upper extremity use due to shoulder immobilization. We converted measured physical activity data into physical activity metabolic equivalents per week (MET-min/week) using the formula proposed by Ainsworth *et al.* [22]. The standard MET value for calculation is 3.3 MET for walking, 4.0 MET for moderate physical activity, and 8.0 MET for vigorous physical activity. Moderate physical activity means activities that require medium physical exertion and make you breathe slightly harder than normal (*e.g.*, fast walking, bicycling at a regular pace). Vigorous physical activity means activities that require hard physical exertion and make you breathe much harder than normal (*e.g.*, fast stair climbing, fast bicycling) [23]. We classified those who achieved 600 MET or more by walking or performing moderate activity five or more days per week or by performing vigorous activities for at least 20 minutes for three days or more per week as the high physical activity (HPA) group. Patients who did not meet the level of physical activity for inclusion in the HPA group were in the low physical activity (LPA) group [24]. We measured all tests required for analysis before and six weeks after surgery.

2.2 Subjective shoulder pain

We used the visual analog scale (VAS) to measure subjective shoulder pain. The VAS is a simple evaluation tool that can visually confirm pain changes by patients, directly indicating the subjective pain level during ADL and exercise [25]. We used a 10-cm line marked with numbers to the decimal point and designated the starting point on the left side of the line as a very relaxed state without pain (0 points) and the right side of the line as the most severe pain state (10 points). The participants directly marked their pain level scores.

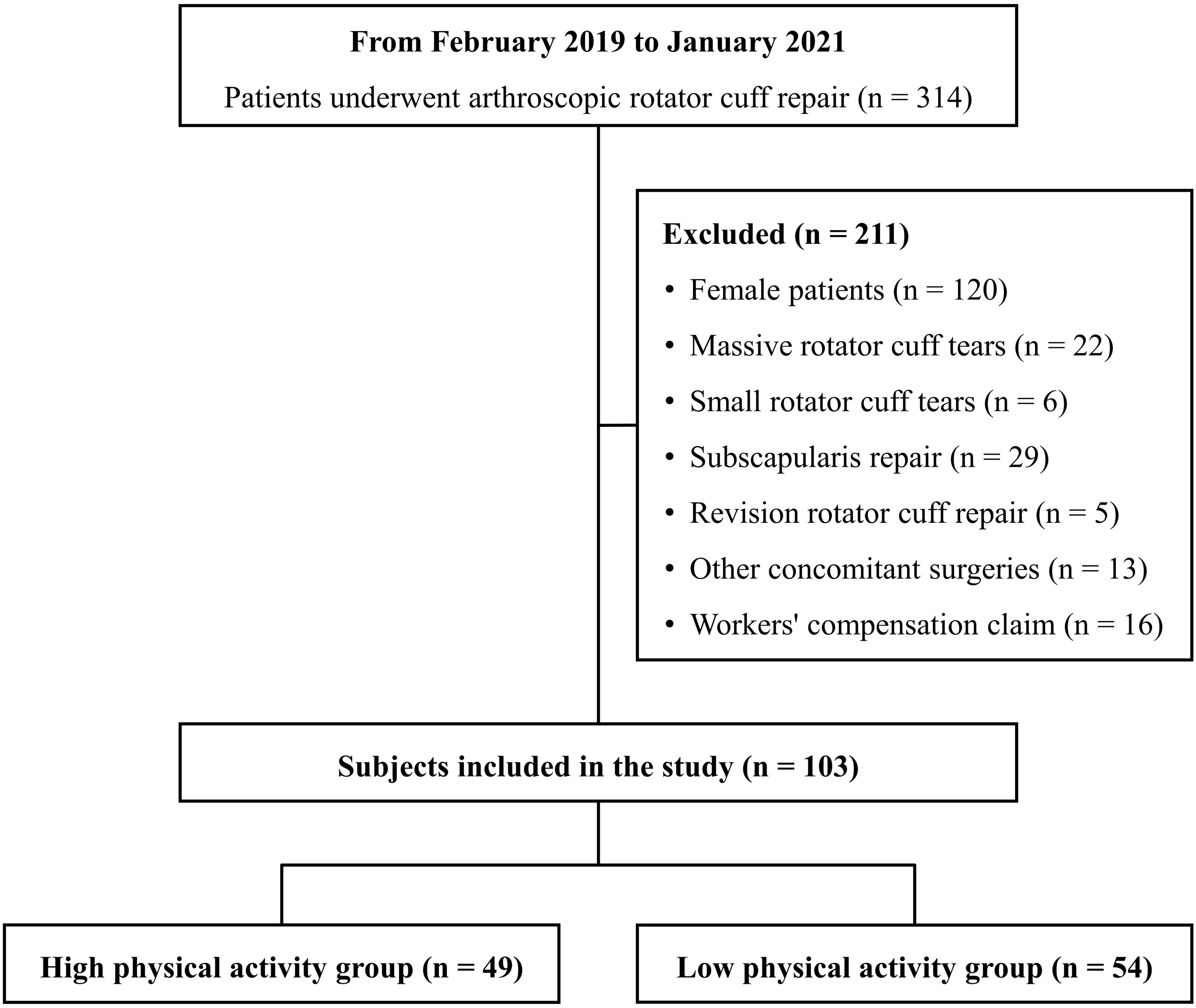

FIGURE 1. Flow diagram of subject selection.

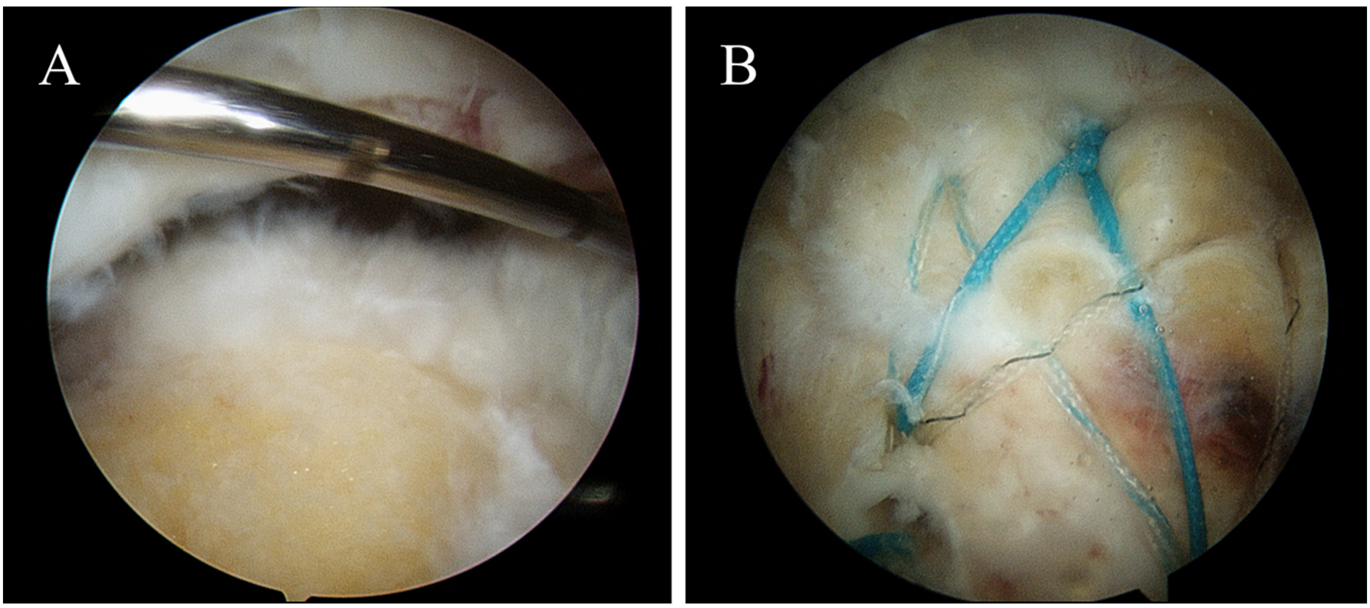

FIGURE 2. Arthroscopic rotator cuff repair. (A) Subacromial decompression. (B) Suture bridge technique.

2.3 Shoulder ROM

We manually measured forward flexion, abduction, and external rotation ROM of shoulder using a goniometer in the supine position [26]. When measuring forward flexion, the goniometer sets the lateral center of the humeral head as a reference point, with the stationary arm aligned with the midaxillary line and the movement arm aligned with the lateral midline of the humerus. When measuring abduction, the goniometer sets the anterior center of the humeral head as a reference point, with the stationary arm aligned parallel to the sternum and the movement arm aligned with the anterior midline of the humerus. We measured external rotation with the upper arm in contact with the side of the torso, and the elbow flexed at 90 degrees. The goniometer set the olecranon process of the elbow as a reference point, with the stationary arm aligned perpendicular to the ground and the movement arm aligned toward the ulnar styloid. We did not measure the internal rotation ROM six weeks after surgery to avoid excessive biomechanical strain on the repaired supraspinatus tendon and excluded it from the analysis. For each measurement, we recorded the angle of the end point of the patient's maximum active ROM, recording the higher value by measuring twice. If the error exceeded 3°, we performed repeated measurements.

2.4 Shoulder function score

We assessed the shoulder function score using the American Shoulder and Elbow Surgeons (ASES) score [27]. A questionnaire consisting of a single item on pain and ten items related to shoulder function determines the ASES score. We converted the total score into a perfect score of 100 by weighting 50% pain and 50% function. Calculating the final pain score involves subtracting the patient-reported VAS score from a score of 10 and multiplying it by 5. For the functional portion, we scored each of the ten individual questions on an ordinal scale of 0 to 3 for a maximum raw functional score of 30 points. Then, we multiplied the raw score by 5 and divided it by 3 again to calculate a functional score of up to 50 points. Finally, we summed the pain and functional portions to obtain the total ASES score. Higher scores indicate better subjective shoulder functional status. The ASES score is reliable and valid in many previous studies, has high reproducibility, and has easy application in clinical practice; therefore, practitioners can use it for almost all shoulder diseases. The intraclass correlation coefficient (ICC) and the the minimal clinically important difference (MCID) reported in previous studies were 0.84–0.96 and 6.4 points, respectively [28].

2.5 Upper extremity strength

We used a digital dynamometer (TKK 5401, TAKEI, Niigata, Japan) to measure upper extremity grip strength. Grip strength is generally compared with normative reference values or used to compare muscle function between dominant and non-dominant limbs. Researchers have reported a correlation between objective measures of general body strength and upper extremity function [29]. A previous study reported a significant positive relationship between isometric grip strength and peak torque values for isokinetic muscle strength of shoulder stabilizing muscles [30]. In addition, Alizadehkhaiyat *et al*. [31] found that a standardized grip force measurement performed in a neutral position activates the supraspinatus and infraspinatus muscles. Subjects were standing, looking straight ahead, and keeping their backs straight. The arms were naturally lowered, the elbows or wrists were not bent, and the arms were not touching the torso. The feet were spread as wide as the pelvis (Fig. 3). They took care not to change the standard posture while measuring grip strength. We adjusted the grip of the dynamometer so that the subject's second joint of the index finger was at 90°. We measured the maximum grip strength twice on each side by crossing both hands, and gave a rest period of 60 seconds between the measurements. To compare the measured grip strength ratio between the involved limb and the uninvolved limb between groups, we calculated the limb symmetry index (LSI) with the following formula:

$$LSI = (Involved\,limb/Uninvolved\,limb) \times 100.$$

2.6 Postoperative rehabilitation

All subjects included in this study followed the same postoperative rehabilitation protocol. In the early rehabilitation phase after ARCR, we particularly emphasized tissue healing, inflammation and pain reduction, and protection of the repaired tendon [32]. Accordingly, the patients in this study wore a shoulder abduction brace (SAB) for six weeks after surgery to fix the shoulder joint in 20° abduction and 30° internal rotation. Therefore, they had restricted shoulder motion and only performed active ROM exercises for adjacent joints such as the neck, elbow, wrist, and hand. In addition, we tried to maintain the centralization of the humeral head by emphasizing the positioning of the scapula, including retraction and depression of the scapula. Rehabilitation began immediately on the first postoperative day. During the hospitalization period, the patients underwent rehabilitation under the supervision of a physical therapist. Patients received instruction to perform rehabilitation exercises three times per day, ten at each time. Upon discharge from the hospital, we strongly recommended that patients perform self-rehabilitation exercises. In addition, we encouraged all patients to perform lower extremity physical activity as often as possible.

2.7 Statistical analysis

We used SPSS Statistics version 25.0 for Windows (IBM Corp., Armonk, NY, USA) for data analysis. We expressed continuous variables as the mean and standard deviation and categorical variables as numbers and percentages. We performed normality tests of the main variables using the Kolmogorov-Smirnov and Shapiro-Wilk tests. We also conducted a nonparametric analysis because the main variables did not show a normal distribution. In addition, we used the Wilcoxon signed-rank test to compare the difference between the pre-and post-results for each group. We compared differences between groups at each time point using the Mann–Whitney U test. We compared the VAS and ASES scores among the analyzed results with the

FIGURE 3. Grip strength test.

MCID reported in previous studies to evaluate their clinical significance. We set the significance level at $p < 0.05$.

3. Results

3.1 General characteristics

The 103 subjects included in this study were in the HPA (n = 49) and LPA (n = 54) groups according to the IPAQ physical activity evaluation criteria. Table 1 shows their general characteristics. As a result of statistical analysis, there were no significant differences in age, height, weight, body mass index, involved side, tear size, and preoperative physical activity volume between groups. However, we noted a significant difference in the postoperative physical activity volume used as the criterion for group classification.

3.2 Subjective shoulder pain

Table 2 shows the changes in subjective shoulder pain after ARCR and the differences between groups. Pain decreased significantly six weeks postoperatively compared to preoperatively in both groups. However, in comparing groups, the HPA group showed a significantly lower VAS score than the LPA group at six weeks postoperatively.

3.3 Shoulder ROM

Table 3 shows the changes in shoulder ROM after ARCR and the differences between groups. In both groups, the ROM in forward flexion, abduction, and external rotation decreased significantly six weeks postoperatively compared to preoperatively. However, between groups, the ROM at six weeks postoperatively was significantly greater in the HPA group than in the LPA group.

3.4 Shoulder function score

Table 4 shows the changes and differences in the ASES score measured to evaluate shoulder function score after ARCR. The HPA group's score increased significantly six weeks postoperatively compared to preoperatively, while the LPA group's score decreased. In addition, we found a significant difference between groups six weeks postoperatively.

3.5 Upper extremity strength

Table 5 shows the changes and differences in grip strength measured to evaluate upper extremity strength after ARCR. The grip strength of the involved limb significantly increased in the HPA group six weeks postoperatively compared to preoperatively, whereas it decreased in the LPA group. There was no significant change or difference in the uninvolved limb. Therefore, the LSI was significantly higher in the HPA group six weeks postoperatively.

4. Discussion

ARCR has been widely used to relieve pain and restore function in patients limited in their ADL due to RCTs, and surgical techniques have significantly improved over the past few decades. However, despite these significant advances, patients still feel it is difficult to return to ADL during the early phase after ARCR due to severe pain and rapid functional decline [8]. Accordingly, practitioners use various therapeutic modalities to relieve pain and promote functional recovery. However, existing pain control methods have potential side effects [9], so patients need safe and effective interventions. Previous studies proposed active physical activity as an effective intervention for pain control. For example, Lannersten *et al*. [15] found a significant reduction in shoulder pain with normal activation of endogenous pain regulatory mechanisms during isometric contractions of the quadriceps muscle in patients with long-term shoulder myalgia lasting more than six months. In addition, Wassinger *et al*. [16] reported that lower extremity aerobic exercise performed on a stationary bicycle immediately reduced mechanically induced shoulder pain. These studies suggest that exercise using non-painful limbs can be an effective alternative to control pain in limbs that are difficult to exercise due to pain. Therefore, this study investigated the effect of physical activity using the lower extremities on shoulder pain and biomechanical and functional recovery in the early phase after ARCR when the physical activity level rapidly decreased due to shoulder immobilization.

This study's results found the HPA group had significantly lower subjective pain six weeks after surgery than the LPA group. We evaluated the MCIDs in VAS scores before and six weeks after surgery for each group to determine whether these results were clinically meaningful. An MCID is the minimal change in a measure that indicates a significant improvement in disease symptoms [33]. For instance, Tashjian *et al*. [33] suggested an MCID of 1.5 points for the VAS score in the pain assessment of patients with rotator cuff disease. In the HPA group, the VAS score decreased by 3.86 points at six weeks after surgery compared with before surgery. This change is a reduction of 2.6 times the MCID suggested in the previous study. On the other hand, in the LPA group, the VAS score decreased by 1.18 points six weeks after surgery, and there was no significant MCID. These results relate to the hypoalgesic effect induced through high levels of physical activity.

Previous studies have found that a hypoalgesic response that reduces pain sensitivity occurs during and after physical activity, and this phenomenon is exercise-induced analgesia (EIA) [34]. Researchers have reported high physical activity levels to produce stimuli that activate descending inhibitory pain systems, including endogenous opioids [11]. In addition, increased physical activity reduces the circulating levels of pro-inflammatory markers such as interleukin (IL)-6 and IL-8 to normal levels [12]. Sluka *et al*. [35] reported that regular physical activity decreased the excitability of central neurons and increased the release of endogenous opioids and serotonin from the brainstem pain inhibitory pathway. In addition, beta-endorphin, a representative endogenous opioid, increases its concentration in the peripheral blood after physical activity and regulates pain by activating the spinal cord inhibitory mechanism through stimulation of peripheral afferent neurons [36]. Serotonin is a major neurotransmitter found in the rostral ventromedial medulla in the brainstem "and is known to play an essential role in pain control [35]. Activation of these endogenous pain control mechanisms mediated by physical activity helps prevent the overuse of oral medications such

TABLE 1. General characteristics of the HPA and LPA groups.

Variables	HPA (n = 49)	LPA (*n* = 54)	t or χ^2	*p*-values
Age, years	59.4 ± 5.8	59.8 ± 6.5	−0.367†	0.715
Height, cm	171.4 ± 3.7	171.8 ± 3.3	−0.498†	0.619
Weight, kg	75.7 ± 4.2	76.4 ± 3.9	−0.896†	0.373
BMI, kg/m^2	25.8 ± 1.5	25.9 ± 1.7	−0.493†	0.623
Involved side, n (%)				
Right	34 (69.4%)	36 (66.7%)	0.087‡	0.768
Left	15 (30.6%)	18 (33.3%)		
Tear size, n (%)				
Medium	20 (40.8%)	23 (42.6%)	0.033‡	0.855
Large	29 (59.2%)	31 (57.4%)		
Physical activity volume, MET·min/wk				
Preoperative	347.4 ± 90.5	370.1 ± 76.3	−1.381†	0.170
Postoperative	1054.0 ± 225.8	388.1 ± 80.8	19.536†	<0.001*

**p* < 0.05; †Analyzed with an independent sample t-test; ‡Analyzed with a Chi-squared test; HPA, high physical activity; LPA, low physical activity; BMI, body mass index; MET, metabolic equivalent of task.*

TABLE 2. Subjective shoulder pain in the HPA and LPA groups.

Variables	Group	Pre-op	Six weeks post-op	Difference (%)	*p*-values†
VAS score					
	HPA	7.80 ± 0.68	3.94 ± 0.66	−49.5	<0.001*
	LPA	7.72 ± 0.86	6.54 ± 0.97	−15.3	<0.001*
	p-values‡	0.657	<0.001*		

**p* < 0.05; †Analyzed with a Wilcoxon signed-rank test; ‡Analyzed with a Mann-Whitney U test; HPA, high physical activity; LPA, low physical activity; Pre-op, preoperative; post-op, postoperative; VAS, visual analog scale.*

TABLE 3. Shoulder range of motion in the HPA and LPA groups.

Variables	Group	Pre-op	Six weeks post-op	Difference (%)	*p*-values†
Forward flexion, degree					
	HPA	136.0 ± 7.6	89.6 ± 6.8	−34.1	<0.001*
	LPA	134.8 ± 7.7	85.1 ± 6.3	−36.9	<0.001*
	p-values‡	0.270	0.001*		
Abduction, degree					
	HPA	114.1 ± 10.4	76.5 ± 6.9	−33.0	<0.001*
	LPA	115.0 ± 9.5	72.0 ± 9.2	−37.4	<0.001*
	p-values‡	0.692	0.005*		
External rotation, degree					
	HPA	37.3 ± 6.0	16.2 ± 5.3	−56.6	<0.001*
	LPA	37.2 ± 6.5	12.9 ± 7.0	−65.3	<0.001*
	p-values‡	0.737	0.001*		

**p* < 0.05; †Analyzed with a Wilcoxon signed-rank test; ‡Analyzed with a Mann-Whitney U test; HPA, high physical activity; LPA, low physical activity; Pre-op, preoperative; post-op, postoperative.*

TABLE 4. Shoulder function score in the HPA and LPA groups.

Variables	Group	Pre-op	Six weeks post-op	Difference (%)	p-values†
ASES score					
	HPA	38.3 ± 6.8	45.4 ± 4.4	18.5	<0.001*
	LPA	38.7 ± 6.6	36.5 ± 4.2	−5.7	0.022*
	p-values‡	0.587	<0.001*		

**p* < 0.05; †Analyzed with a Wilcoxon signed-rank test; ‡Analyzed with a Mann-Whitney U test; HPA, high physical activity; LPA, low physical activity; Pre-op, preoperative; post-op, postoperative; ASES, American Shoulder and Elbow Surgeons.*

TABLE 5. Upper extremity strength in the HPA and LPA groups.

Variables	Group	Pre-op	Six weeks post-op	Difference (%)	p-values†
Involved side Grip strength, kg/BW, %					
	HPA	45.1 ± 2.4	46.7 ± 2.6	3.5	<0.001*
	LPA	45.0 ± 2.7	43.1 ± 2.9	−4.2	0.003*
	p-values‡	0.822	<0.001*		
Uninvolved side Grip strength, kg/BW, %					
	HPA	55.3 ± 3.0	55.5 ± 2.9	0.4	0.412
	LPA	55.0 ± 3.3	54.9 ± 3.2	−0.2	0.771
	p-values‡	0.687	0.443		
LSI, %					
	HPA	81.7 ± 1.4	84.2 ± 1.7	3.1	<0.001*
	LPA	81.8 ± 1.7	78.4 ± 2.0	−4.2	<0.001*
	p-values‡	0.386	<0.001*		

**p* < 0.05; †Analyzed with a Wilcoxon signed-rank test; ‡Analyzed with a Mann-Whitney U test; HPA, high physical activity; LPA, low physical activity; Pre-op, preoperative; post-op, postoperative; LSI, limb symmetry index.*

as oral opioid analgesia and nonsteroidal anti-inflammatory drug—medical providers traditionally use these drugs for pain control in patients who have undergone ARCR.

This study found a significant decrease in the ROM in forward flexion, abduction, and external rotation decreased six weeks after surgery in the HPA and LPA groups compared with before surgery. This significant reduction in shoulder ROM results from the strictly recommended shoulder immobilization immediately after surgery. All subjects in this study followed the same rehabilitation protocol and restricted the movement of the glenohumeral joint by wearing an SAB until six weeks after surgery. Most of the literature recommends shoulder immobilization for four to six weeks after surgery for patients who have undergone ARCR [14, 37, 38]. This result is related to the problems of limited ADL and decreased physical activity levels in the early phase after ARCR. Nevertheless, surgeons strictly recommend shoulder fixation during the early stage to minimize tension on the repaired tendon. In the past, practitioners believed that starting passive motion immediately after surgery helped reduce postoperative joint stiffness. However, recent studies have reported that immediate postoperative immobilization presents a greater advantage for tendon-bone healing and that rapid postoperative passive motion may be detrimental to tendon healing [39]. Van *et al*. [14] reported that stably fixing the glenohumeral joint for four to six weeks in a slightly abducted position in the scapular plane could minimize the tension on the repaired tendon and maximize vascularization. However, since such shoulder immobilization causes unavoidable shoulder stiffness, patients may still feel difficulty in ADL even after removing the brace.

Interestingly, patients in the HPA group, who performed lower extremity physical activity at a high level, showed a significantly greater ROM in forward flexion, abduction, and external rotation six weeks after surgery than those in the LPA group. These results relate to the significant difference between groups in the analysis of subjective shoulder pain according to physical activity level. While measuring the shoulder ROM, the patients recognized the end ROM that they could comfortably move as the last point of discomfort that did not cause pain. Therefore, the hypoalgesic effect in the group with a high level of physical activity may have affected the difference in shoulder ROM between the groups. Patients with higher subjective pain sensitivity had more narrow shoulder ROM. Patients stopped moving their shoulders when they felt pain at the end of their possible range of motion, and the earlier they felt pain, the stiffer their shoulders became. Shoulder ROM is closely related to ADL and work [40]. Although the ROM in both groups decreased compared to before surgery, the fact that the HPA group showed less limitation of shoulder movement suggests that active physical activity is vital for patients to return to daily activities early.

Previous studies have suggested several patient-reported outcome tools to facilitate functional diagnosis and characterize the ADL limitations in patients who underwent ARCR

[28]. Functional outcomes measured as subjective scores can contribute to clinical diagnosis and assess the effectiveness of applied interventions [41]. In addition, it can help determine the level of compromise for participation in ADL and work. Researchers commonly use the ASES score as a tool to score and measure the subjective shoulder symptoms and function of patients after ARCR [42]. The ASES score in this study significantly improved in the HPA group six weeks after surgery compared with before surgery, but the LPA group's score significantly decreased. Furthermore, the HPA group showed a significantly higher ASES score than the LPA group six weeks after surgery.

We investigated the clinical significance of these results by evaluating the MCID for the change in the ASES score for each group. A previous study proposed the MCID of the ASES score to assess the functional recovery of patients with rotator cuff disease to be 6.4 points [28]. In the results of this study, the HPA group showed a significant MCID with a score that increased by 7.2 points six weeks after surgery. These results relate to the considerable difference between the two groups' VAS score and ROM measurement at six weeks postoperatively. Shoulder pain is a factor associated with the prognosis for return to work or job retention, including limitation of ADL [43]. The HPA group reported significantly reduced subjective pain six weeks postoperatively compared to preoperatively, which may have led to higher self-reported outcomes in pain-related subscales of the ASES score. In addition, the function-related items, which account for the remaining 50%, include activities that are complexly related to pain and ROM. Because loss of shoulder ROM closely relates to limited ADL, many interventions focus on improving the damaged ROM early after surgery [44]. At six weeks postoperatively, the ROM in both groups decreased compared to preoperatively, but the HPA group showed a greater ROM than the LPA group. This difference may have affected the reporting of relatively high scores on items related to ADL and tasks.

In general, therapists use isokinetic strength testing to evaluate shoulder muscle function in patients who have undergone ARCR [45]. However, due to the nature of the examination in which the patient must exert maximum muscle strength of the directly involved limb, applying excessive tension to the repaired tendon attachment may negatively affect the healing process. Therefore, considering the healing process, there is a limitation in that the examination can occur only after at least 12 weeks postoperatively [46]. However, the therapist can use the grip strength test to measure the level of muscle function of the upper extremities even in the early phase after surgery because there is little risk of tension at the surgical site [29]. Therefore, this study measured grip strength to assess the upper extremity strength of the involved limb. In addition, we referred to Horsely *et al.*'s [29] study to evaluate the clinical significance of the grip strength values between the involved and uninvolved limbs by converting the values into the LSI for analysis. As a result of the analysis, the LSI for grip strength of the involved limb significantly improved in the HPA group six weeks after surgery, whereas that in the LPA group significantly decreased. Furthermore, the HPA group showed a significantly higher LSI six weeks after surgery than the LPA group. Previous studies reported that shoulder pain is significantly associated with the reduced grip strength of the involved limb [47]. Moreover, nociceptive activity associated with shoulder pain may affect the distant muscles' sensitivity and motor activity at similar segmental levels [48]. In the HPA group, shoulder pain decreased significantly six weeks postoperatively, and we think this result partially relates to increased grip strength. In addition, physical activities that use the major muscle groups of the lower extremities, such as walking, climbing stairs, and stationary cycling, increase blood flow to inactive muscle tissues and organs due to increased sympathetic nervous activity [49]. This evidence suggests that physical activity using the lower extremities in the early postoperative phase when shoulder motion is limited after ARCR can potentially affect the functional recovery of the upper extremity.

This study has several limitations. First, since this is a retrospective study, we cannot exclude the possibility of bias. Furthermore, the small sample size may make it difficult to generalize the results. In addition, we limited the subjects in this study to males to control for sex differences as a confounding factor affecting the results. However, since females have higher pain sensitivity than males due to differences in neuroprocessing and hormones in pain-inhibitory brain regions [50], there is a possibility that results may differ from males; therefore, we need additional research involving females. In addition, in this study, we could not control the type and method of physical activity because we classified the physical activity level by evaluating the MET based on the IPAQ reported by the patients. Therefore, future research could determine the exact intensity and frequency of exercise affecting the biomechanical and functional outcomes after ARCR by conducting a randomized controlled trial that controls the type and method of exercise the patient performs.

5. Conclusions

In this study, patients with higher levels of lower extremity physical activity after ARCR showed lower subjective pain and faster biomechanical and functional recovery than those with lower levels of physical activity. Therefore, even if the involved shoulder has restricted use in the early phase after ARCR, it is crucial to actively recommend continuing physical activity, including walking, stationary cycling, and climbing stairs using the lower extremities.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

MYC and JWC—designed the study. MYC—collected and analyzed the data. MYC and JWC—interpretated the results. JWC—provide advice and supervise in experiments. MYC—wrote the manuscript. JWC—reviewed and edited the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the researcher's institutional review board (approved number: PAIK 2021-04-009). All patients provided written informed consent.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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