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An additional rehabilitation program to improve postoperative outcomes in patients with rotator cuff tear and scapular dyskinesis: a propensity score-matched study

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Abstract

Background General scapular exercises have been included in traditional postoperative rehabilitation for rotator cuff tears, but patients with concomitant scapular dyskinesia do not have identical scapular muscle imbalances, and general scapular exercises make it difficult to improve scapular movement. We hypothesized that identifying weak scapular muscle groups and strengthening training would improve scapular movement.

Methods A total of 60 rotator cuff tear patients with scapular dyskinesia were included in the study, 20 in the experimental group and 40 in the control group. Patients in the control group received traditional rehabilitation following rotator cuff repair, while patients in the experimental group performed additional selective scapular muscle rehabilitation exercises. Constant-Murley Score (CMS), shoulder mobility, VAS scores, SF-12 scores, and scapular motion were assessed in both groups at 16 weeks postoperatively.

Results At 16-week follow-up, the experimental group showed better CMS (87.2 ± 4.4 vs. 83.9 ± 4.8) and shoulder anteflexion (137 ± 13.0 vs. 127.9 ± 12.2°) and abduction mobility (133.1 ± 15.4 vs. 121.4 ± 13.8°) compared to the control group. The experimental group had better improvements in scapular upward rotation (42.8 ± 11.7 vs. 35.3 ± 9.6°) and anterior tilt (12.9 ± 4.2 vs. 6.4 ± 2.0°) during shoulder anteflexion versus the control group. During shoulder abduction, the experimental group had better improvements in scapular anterior tilt (12.8 ± 3.3 vs. 9.1 ± 3.0°) versus the control group.

Conclusions This study provides an additional exercise program targeting the scapular muscle groups for postoperative rehabilitation in rotator cuff tear patients with scapular dyskinesis. By identifying imbalanced muscles through electromyographic testing, and performing selective muscle strengthening exercises, better shoulder mobility and scapular motion performance can be achieved.

Trial registration (Chinese Clinical Trial Registry (https://www.chictr.org.cn), ChiCTR2400087465, July 29, 2024, prospectively registered.)

Keywords Shoulder, Rotator cuff injury, Scapular dyskinesis, Postoperative

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Introduction

Rotator cuff tears is one of the most common shoulder injuries, with its incidence increasing annually [1]. The scapula is a critical component of shoulder joint movement, and many shoulder joint lesions are associated with scapular dyskinesis (SD) [2]. The causal relationship between SD and rotator cuff tears is still under debate, however, the importance of restoring normal scapular motion to improve shoulder function is indisputable [3–5]. SD is a nonspecific response to painful conditions in the shoulder rather than a specific response to certain shoulder pathologies. This dyskinesis alters the scapula's role in the scapulohumeral rhythm, interfering with normal shoulder motion, and this effect is amplified in patients with rotator cuff tears [6].

SD is defined as an abnormality of scapular position and movement, primarily manifested by abnormalities in the appearance and shape of the scapula or a lack of coordinated movement during activities of shoulder flexion and adduction [7]. SD is closely associated with abnormal activation of the scapular muscles, including alterations in the timing of muscle tissue activation and muscle strength [8]. The utilisation of wireless surface EMG technology enables the precise documentation of alterations in the activation status of a patient's musculature, thus facilitating the accurate identification of anomalous muscle groups [9]. It has been demonstrated that patients presenting with aberrant scapular dynamics frequently display heightened or premature activation levels of the upper trapezius (UT), while the serratus anterior (SA), middle trapezius (MT), and lower trapezius (LT) exhibit reduced activation or delayed muscle excitation [10, 11]. A reduction in muscle strength or a decrease in the activation of the periscapular muscle groups can result in an alteration of the scapular motor function, which may manifest as a variety of scapular dyskinesis.

After rotator cuff repair surgery, traditional rehabilitation procedures focus on increasing shoulder mobility and improving muscle strength, with few procedures used to improve scapular motion [12, 13]. This partly explained the lower postoperative function of rotator cuff repair in patients with scapular dyskinesia, as general scapular exercise program had limited improvement in activation of abnormal scapular muscle groups [4]. There has been a gradual increase in research on scapular exercise in recent years, but there has been little research on the optimal approach to scapular rehabilitation after rotator cuff repair in patients with rotator cuff tears and scapular dyskinesia [14, 15]. Yuksel et al. [16] investigated the effects of scapular stabilization exercises in patients with subacromial pain syndrome. He found that the addition of scapular stabilization exercises was effective in improving scapular dyskinesis, reducing pain, increasing muscle strength and improving shoulder function. Almeida [17] found that preoperative additional scapular and core stabilization exercises had a positive impact on recovery after arthroscopic repair of traumatic rotator cuff injury. However, Kamonseki [18] believe that scapular movement training, including wall slides, arm elevation with elbow flexion, arm elevation with elbow extension, and arm elevation with a dumbbell, is not superior to standard exercises for improving scapular biomechanics, behavioral, and clinical aspects in people with shoulder pain. Our study differs from previous studies in that our intervention required a combination of postsurgical physical therapy protocols and additional scapular exercises for 16 weeks after rotator cuff repair. To enhance the efficacy and security of postoperative exercise, a targeted scapular muscle exercise program was developed based on the patient's preoperative EMG results.

The objective of this study was to ascertain whether the implementation of the additional scapular exercise program, conducted 16 weeks following rotator cuff repair, would enhance shoulder functionality, scapular motion and shoulder motion in a population exhibiting scapular dyskinesis.

Methods

A total of 60 patients were enrolled in this study. Patients in the experimental group underwent preoperative shoulder muscle surface electromyography (EMG) examination to identify muscle groups with abnormal activation, followed by targeted scapular movement rehabilitation exercise. Patients in the control group were selected via propensity score matching (1:2) from other patients in the same time period.

Inclusion Criteria:

1. Failure of nonsurgical treatment (i.e., persistent pain and/or disability after 3 months of conservative treatment, including analgesic/anti-inflammatory medications, intra-articular corticosteroids, activity modification, and physical therapy);
2. Full-thickness rotator cuff tear involving the supraspinatus tendon verified by arthroscopic surgery and repairable;
3. Concomitant scapular dyskinesis; (dynamic scapular dyskinesis test is necessary, scapular movements were observed during shoulder flexion and abduction; uncoordinated movements and abnormal protrusion of the margins were recorded. any deviation from the norm is noted as dyskinesis is present. the scapular assistance test and the scapular repositioning test were used to further clarify the diagnosis.)

Exclusion Criteria:

1. History of previous shoulder joint surgery;
2. Significant comorbidities that impair limb control, such as brachial plexus injury, Parkinson's disease, etc.;
3. Other shoulder joint diseases, including anterior inferior labrum (Bankart) lesion, severe glenohumeral arthritis, adhesive arthritis, etc.;
4. Refusal or inability to complete the study follow-up or incomplete follow-up data;

Study design

The physicians conduct a preliminary screening and refer patients awaiting surgery to the principal investigators. The principal investigators perform a final eligibility evaluation and furnish the patients with comprehensive information pertaining to the research. Following obtaining written consent, a baseline assessment is conducted 1–14 days prior to the surgery. The included patients were compared with a propensity score-matched group of patients who met the inclusion and exclusion criteria for this study within the same time frame. The only difference was that patients in the control group did not perform additional scapular exercises. Patients in both groups were assessed for recovery at 16 weeks postoperatively. All procedures were conducted in accordance with the Declaration of Helsinki. Ethical approval for data collection, reporting, and participant involvement was granted by the Ethics Committee of The First Affiliated Hospital of Fujian Medical University (Approval No.: MRCTA, ECFAH of FMU [2024]374). Written informed consent was obtained from all participants prior to enrolment.

Surgery procedure

Under general anesthesia, arthroscopy confirmed the full RC tear, including dimensions, tendon contraction, and tissue quality. All patients underwent arthroscopic subacromial decompression to obtain a flat subacromial surface. Biceps tenodesis or tenotomy was performed for dislocation, subluxation, or tears involving more than 50% of the long head of the biceps, based on age or activity level. Arthroscopic repair was performed according to the morphology and extent of the tear, and the tear margin was debrided to obtain better quality tendons. Single-row or double-row suture bridge repair techniques were applied to ensure satisfactory rotator cuff suture and fixation.

Test procedure

EMG test: Participants are required to undergo familiarization exercises for the upcoming test movements to ensure accurate execution of the movement patterns. The participants were asked to adopt a standing posture, while holding a 1 kg weight. They were then instructed to keep the elbow joint straight, raise the upper limb as far as possible in the plane of the scapula, and then lower it. This sequence of actions was to be repeated on five occasions.They expose their upper bodies and begin by cleansing the target muscle bellies and surrounding skin. The monitoring skin area disinfection was performed using 75% alcohol, wait for the alcohol to evaporate and the area to become dry before attaching the sensors (Noraxon MyoMotion, Noraxon USA Inc.). This helps reduce the impact of skin resistance ($<10\Omega$) on the EMG signals. EMG signals of 4 scapular muscles UT, MT, LT, and SA (upper/middle/lower trapezius, serratus anterior) were measured during test. The placement of surface EMG is based on the recommendation of SENIAM (Surface Electromyography for the Non-invasive Assessment of Muscle) [19]. The EMG data were further confirmed for data accuracy and reliability and data with poor acquisition quality were reacquired. The EMG signals were systematically processed using the Noraxon platform. First, the EMG signals were filtered using an Finite Impulse Response (FIR) band-pass filter with a bandwidth of 20–450 Hz. Subsequently, after full - wave rectification is performed, the EMG signals are smoothed via the root - mean - square (RMS) smoothing algorithm with a window length of 100 milliseconds. Finally, maximum normalization is carried out to generate the envelope. The MVC value (100%) used to normalise the EMG signal of each muscle. The data for each muscle and participant were averaged over the 5 intermediate repetitions. The MVC value of each muscle was used for normalisation of the EMG values of the exercises.

Patients in the control group were not required to participate in EMG testing, but 12 healthy subjects without SD were invited to undergo the same EMG testing process, with results used as a standardized template for comparison with the experimental group. Healthy subjects were recruited by a specialist physician who confirmed normal shoulder and scapular motion and no history of musculoskeletal disorders or trauma of the shoulder. Healthy subjects were not statistically different from the experimental group in terms of age, gender and BMI.

Scapular kinematics: We used a scapular wireless inertial sensor measurement device to track the scapular kinematics during shoulder anteflexion and abduction activities [20]. The scapular measurement device consists of a tripod positioner (positioning the angulus inferior, angulus acromialis and trigonum scapulae) and an IMU inertial sensor (Witmotion, China, with an accuracy of 0.2 degrees and an acquisition frequency of 200 HZ, the accuracy of the device has been verified [21, 22]). Figure 1 Participants were asked to expose their backs and slowly flex and abduct their upper limbs, with the measurer held the device behind the patient as accurately as

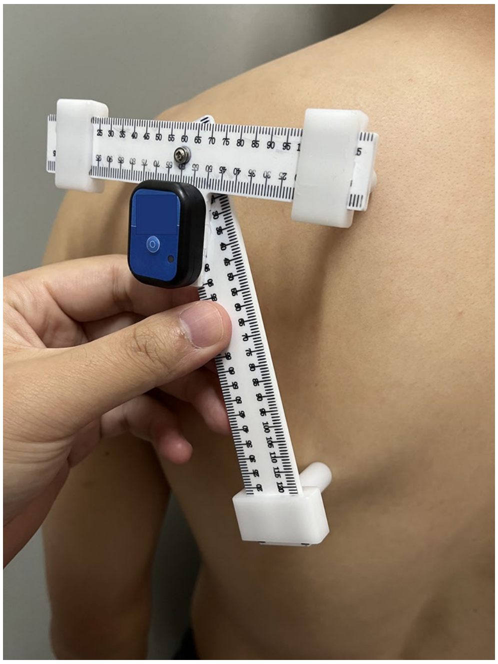


Fig. 1 Scapular wireless inertial sensor measurement device

possible close to the anatomical landmarks (angulus inferior, angulus acromialis and trigonum scapulae) of the scapula and matching the movement. Additionally, an IMU sensor is worn on the measured upper limb to synchronize and correlate the relationship between upper arm mobility and scapular position.

Rehabilitation procedure

Control group: The patients in the control group received the conventional rehabilitation exercise program after rotator cuff repair surgery. The purpose of early rehabilitation is to increase the shoulder joint mobility and prevent adhesion, and to increase the weight-bearing in the later rehabilitation to reduce muscle atrophy. Patients in the control group received general scapular exercises, which consisted mainly of scapular relaxation and stabilisation exercises. Patients followed up in the outpatient clinic at 2, 6, and 12 weeks postoperatively for joint mobility, pain, and muscle strength. Based on follow-up results, the physician recommended the next rehabilitation program. The routine rehabilitation program included wall climbing exercises in the coronal and sagittal planes, dorsal extension exercises, and closed-chain exercises for door pushing. In the first 3 weeks, the shoulder was immobilized in a brace, with passive movement started in the 4th week, and active shoulder movement in the 6th week, The range of motion and weight bearing were gradually increased thereafter.

Experimental group: Patients in the experimental group completed EMG testing prior to surgery. EMG results of the patient help identify whether the muscle activation leading to SD is excessively high or low. EMG results from each patient in the experimental group were analysed individually to confirm activation of abnormal scapular muscles. The discrimination of weak muscles or abnormally activated scapular muscle groups was performed jointly by two physicians and a statistician. Discrimination of the weak muscle was based on the measured activation rates of each muscle (UT, MT, LT, SA) and the activation ratios of the main scapular antagonist muscle groups (UT/MT, UT/LT, UT/SA).

Besides the standard rehabilitation program for the control group, patients in the experimental group underwent a personalized exercise regimen targeting the weak scapular muscles. The additional rehabilitation program consists of a general scapular relaxation and stabilisation exercises + four basic and advanced selective scapular muscle exercises. We recommend a program of at least 20 repetitions of each standard cycle 3 times a day. Each patient's rehabilitation program is determined jointly by the surgeon and the physiotherapist. After the patient has received the rehabilitation plan, the physiotherapist instructs and supervises the rehabilitation exercises. As an additional program, the timing and frequency of exercise were the same as in the control group. The specific workout flow is shown in the diagram. Table 1.

Shoulder motion rehabilitation after rotator cuff repair should be performed with sufficient caution, especially with the added burden of shoulder motion, which may increase the patient's discomfort and risk of re-tear. In order to mitigate injury risks, patients can utilize a remote app for accessing their rehabilitation program, enabling them to report rehabilitation progress and receive real-time guidance from a professional physiotherapist.

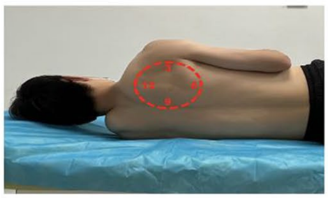
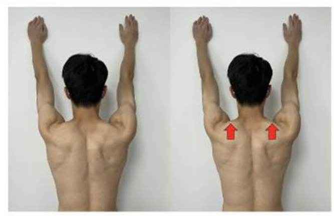
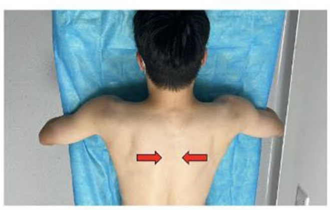
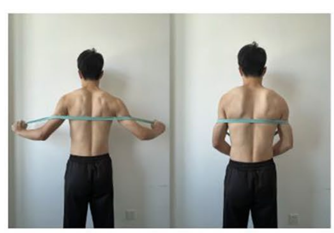
Propensity score–matched analysis

To minimize the potential impact of confounding factors, propensity score matching was performed using R version 4.1.0 (R Core Team). Controlling for age, sex, and BMI, patients in the experimental group were propensity score-matched in a 1:2 ratio to control group. For this process of matching, patients in the control group can only be matched to a participant in the experimental group once. A caliper of 0.2 was used to ensure a precise match.

Surgical outcome tools

The primary outcome was the change in the Constant–Murley Score (CMS) from baseline to 16-week post-operatively. Secondary outcomes included pain scores (VAS), shoulder mobility of the affected shoulder, quality of life scores (SF-12), and scapular movement. Evaluators were unaware of patient groupings and rehabilitation programs.

Table 1 Exercise description

Target muscles	Basic	Advanced	Description
General			Encourage the patient to move and maintain the scapula in multiple directions in lateral and prone positions to increase flexibility and stability of the soft tissues around the scapula.
Upper trapezius			In the basic exercise, the patient feels the upper trapezius muscle firing to drive the scapula up. In the advanced exercise, the patient continues to elevate the scapula with the upper limb flexed as much as possible.
Middle trapezius			In the basic exercise, the patient clenches the scapulae on both sides as much as possible in the prone position. In the advanced exercise, the patient clenches the scapulae against resistance.
Lower trapezius			In the basic exercise, with the shoulders in a neutral position and the elbows bent at 90°, start the external rotation movement from the abdomen. In the advanced exercise, countering resistance in the scapular plane obliquely
Serratus anterior			In the basic exercise, encourage patients to perform multi-directional glass wiping exercises; In the advanced exercise, Perform upper body arm pinch and tightening resistance exercises

Statistical analysis

The sample size calculations were conducted using the G*Power software (3.1, Germany), based on the results of the CMS score after surgery, with an effect size of 0.79. Accordingly, assuming a type I error of 5% and power of 80%, with propensity score-matched in a 1:2 ratio, the experimental group should include at least 20 participants.

Statistical analysis was conducted using IBM SPSS 27.0 software (Chicago, USA). Age and scores for CMS and VAS were presented as mean ± standard deviation ($\overline{X} \pm s$). The Shapiro-Wilk test was used to assess normality of the data. Student's t-test was used to compare normally distributed data between groups, the Mann-Whitney test for non-normally distributed data, and the chi-squared test for differences in composition ratios.

To calculate normalized EMG activity (MVC%) for all muscles, raw EMG activity during exercises was divided by MVC for each specific muscle and multiplied by 100 The MVC% of the target muscles was calculated individually for each subject. Finally, the results of each group were presented as the mean ± standard deviation ($\bar{X} \pm s$). The data were not normally distributed, therefore, an analysis of variance (ANOVA) was used to determine if there were any significant differences in EMG activity and muscle ratios between exercises for each muscle. Scapular motion trends were smoothed using a non-parametric regression method (LOWESS) using locally weighted linear regression to smooth the data. Nonparametric tests

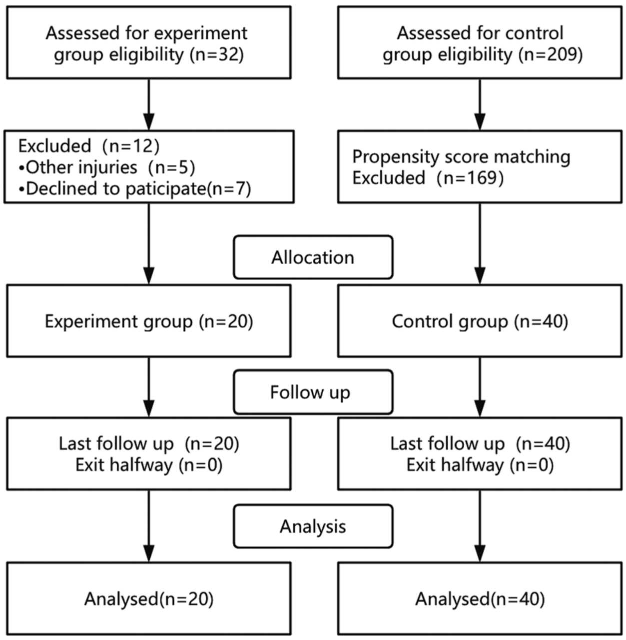


Fig. 2 Study flow chart

Table 2 The demographic characteristics of the patients in the experimental group and the control group

	experimental group (*N*=20)	control group (*N*=40)	*P*
Age(year)	55.4±9.2	59.8±9.9	0.099
Gender(male/female)	9/11	16/24	0.711
BMI(kg/m^2)	24.2±3.5	24.2±2.2	0.489
Surgical side (left/right)	7/13	11/29	0.550
CMS	67.3±8.5	68.3±8.6	0.656
PCS-12	42.3±7.4	42.4±7.4	0.960
MCS-12	42.8±8.8	41.9±6.9	0.696
VAS (0–10;10=most pain)			
pain at rest(now)	1.3±0.7	1.6±1.0	0.235
pain during activity	4.8±0.8	4.4±1.2	0.168
worst pain (past 24 h)	5.7±2.2	5.2±2.0	0.639
ROM(°)			
anteflexion	98.1±19.8	104.2±17.1	0.253
abduction	87.4±10.3	91.2±12.3	0.215

BMI: Body Mass Index; CMS: Constant-Murley Score; PCS: Physical Score; MCS: Mental Score; VAS: Visual Analogue Scale; ROM: Range of Motion

were used to compare the differences in maximum range of motion of the scapula in the transverse, sagittal, and frontal planes between groups of patients. $p<0.05$ was significant.

Results

A total of 60 patients were enrolled in this study, with 20 in the experimental group and 40 in the control group. The study flow chart was shown in Fig. 2. The general information of the patients in both groups is shown in Table 2. 20 patients in the experimental group received complete follow-up and completed the expected rehabilitation program.

The target muscles for scapular rehabilitation of include the upper middle and lower trapezius muscles as well as the serratus anterior. Strengthening exercises for these muscles are based on EMG results with a focus on less activated muscles. The EMG results and the type of rehabilitation program received by the patients in the experimental group are shown in Table 3.

Of the participants, five received exercises targeting the upper trapezius, four targeted the middle trapezius, 4 targeted the lower trapezius, and 7 targeted the serratus anterior.

The average CMS score for the experimental group patients increased by 20 points in the final follow-up compared to pre-surgery, while the control group only increased by 15.7 points. Postoperatively, the study group patients had significantly better shoulder joint function scores than the control group (87.2±4.4 vs. 83.9±4.8, $p=0.012$), but did not exceed the minimum clinically important difference (MCID: 10.4) [23]). The difference in shoulder function between the two groups was not clinically significant. We also found advantages in shoulder anteflexion (137±13.0 vs. 127.9±12.2°, $p=0.010$) and abduction mobility (133.1±15.4 vs. 121.4±13.8°, $p=0.007$) in the study group. Table 4.

We did not find additional scapular muscle rehabilitation to be superior to conventional rehabilitation in improving VAS scores and SF-12 scores.

We found that in patients who underwent rotator cuff repair surgery, the experimental group had greater

Table 3 Preoperative EMG results and targeted exercise muscles in the experimental group

Target	UT		MT		LT		SA		UT/MT		UT/LT		UT/SA	
muscles	***MVC%***	***P***	***MVC%***	***P***	***MVC%***	***P***	***MVC%***	***P***		***P***		***P***		***P***
UT(*N*=5)	44.7±2.8	***0.018****	51.3±5.9	0.111	48.8±4.5	0.725	51.2±9.8	0.664	0.9±0.1	***0.013****	0.9±0.1	0.087	0.9±0.2	0.241
MT(*N*=4)	49.5±4.3	0.896	36.8±2.8	***0.037****	41.3±5.8	0.324	44.1±8.0	0.385	1.4±0.3	0.270	1.2±0.2	0.563	1.2±0.3	0.521
LT(*N*=4)	51.0±6.1	0.742	49.5±6.2	0.271	33.5±8.9	0.110	48.2±11.6	0.936	1.1±0.6	0.206	1.6±0.5	0.134	1.1±0.2	0.948
SA(*N*=7)	49.5±4.2	0.884	49.1±4.7	0.199	46.1±11.5	0.957	25.8±8.8	***<0.01****	1.0±0.1	0.148	1.1±0.3	0.994	1.2±0.3	***0.041****
Standard (*N*=12)	49.8±4.8		44.5±10.4		46.4±14.1		48.8±10.8		1.2±0.5		1.1±0.3		1.1±0.3	

N: number of subjects; UT: upper trapezius; MT: middle trapezius; LT: lower trapezius; SA: serratus anterior; MVC: maximal voluntary contraction; N: number; *:$P<0.05$; standard: healthy individuals electromyography results

Table 4 Postoperative data of patients in both groups

	experimental group (*N* = 20)	control group (*N* = 40)	*P*
CMS	87.2 ± 4.4	83.9 ± 4.8	***0.012****
SF-12			
PCS-12	49.2 ± 7.7	51.7 ± 6.3	0.216
MCS-12	45.7 ± 5.7	46.5 ± 5.0	0.618
VAS (0–10;10 = most pain)			
pain at rest(now)	0.7 ± 0.5	1.0 ± 0.8	0.147
pain during activity	1.8 ± 0.9	2.1 ± 1.2	0250
worst pain (past 24 h)	2.4 ± 0.9	2.4 ± 1.3	0.933
ROM(°)			
anteflexion	137.4 ± 13.0	127.9 ± 12.2	***0.010****
abduction	133.1 ± 15.4	121.4 ± 13.8	***0.007****

CMS: Constant-Murley Score; PCS: Physical Score; MCS: Mental Score; VAS: Visual Analogue Scale; ROM: Range of Motion;

improvements in scapular upward rotation (42.8 ± 11.7 vs. 35.3 ± 9.6°, healthy participant 52.8 ± 13.7°) and anterior tilt (12.9 ± 4.2 vs. 6.4 ± 2.0°, healthy participants 18.7 ± 5.0°) during shoulder anteflexion compared to the control group. During shoulder abduction, the experimental group had greater improvements in scapular anterior tilt (12.8 ± 3.3 vs. 9.1 ± 3.0°, healthy participants 20.5 ± 4.5°) compared to the control group. We did not find any significant differences in improving scapular retraction/protraction between the two groups, but both groups showed significant improvements in scapular movement compared to pre-surgery. Figure 3.

Discussion

The aim of this study was to investigate whether an additional scapular exercise could improve clinical outcomes in patients with rotator cuff tears and scapular dyskinesia 16 weeks after surgery. To our knowledge, this is the first study to develop exercises for weak scapular muscles based on preoperative electromyographic findings early in rehabilitation. We found that additional scapular exercises had the potential to improve shoulder motion and scapular movement, but had limited improvement in shoulder function. Our findings may help clinicians with clinical reasoning and exercise selection after surgery in patients with scapular dyskinesia.

Rotator cuff repair improved the biomechanical structural stability of the shoulder joint, and repair of the supraspinatus muscle benefits the glenohumeral joint center of rotation and the deltoid muscle force arm during shoulder motion [24–26]. A series of studies [27, 28] had confirmed that scapular motion performance improved after rotator cuff repair surgery, but this improvement is not significant in patients with larger tears. The activation pattern of the scapular muscles improved mainly through rehabilitation exercises, and we believed that rotator cuff repair is a good time to address this because the surgery improved the biomechanical conditions of the shoulder joint. Early scapular rehabilitation exercises after rotator cuff repair should be performed with sufficient caution, and the identification of activation patterns in imbalanced muscle groups was crucial for developing an effective rehabilitation program. Investigation of the activation patterns of these muscles through preoperative EMG findings provided clinicians with guidance on selecting a rehabilitation program [29, 30]. Confirmation of optimal muscle activation ratios (relative activity of synergistic muscle groups, as opposed to absolute activity) was crucial for improving scapular muscle strength and balance. In the early stages, risky strength exercises and mobility exercises were prohibited, which might affect the stability of suture anchors and tendon-bone healing. Strengthening weaker-activated scapular muscles and inhibiting over-activated muscles helped restore muscle activation balance.

The most common cause of SD was an imbalance in scapular muscle activation, and previous studies [31–33] had utilized surface electromyographic signals (EMGs) to detect the activation patterns of the superficial scapular muscles, with results showing that optimal agonist and antagonist muscle activation was essential proper shoulder joint biomechanics. Cools et al. [34] study proposed an exercise program consisting of 4 movements to optimize scapular muscle balance: side-lying external rotation [ER], side-lying anteflexion, prone horizontal abduction with ER, and prone extension. The research demonstrated successful activation of the middle trapezius (MT) and lower trapezius (LT) muscles, while the upper trapezius (UT) muscle had low activation. As a result, these exercises might be beneficial for patients with shoulder complaints associated with overactive UT and underactive MT and/or LT muscles. Proper activation of the trapezius and serratus anterior muscles during active shoulder anteflexion and abduction is necessary for optimal scapular motion and stability. Most patients with shoulder pain had over-activation of the upper trapezius and decreased or delayed activation of the middle and lower trapezius and serratus anterior muscles [35]. This abnormal activation pattern mainly affected shoulder joint mobility, and was closely related to the reduction of the subacromial space, which might cause rotator cuff tears [36].

The strength of this study lay in the identification of imbalanced muscles via surface electromyography and postoperative restoration of motor balance in scapular muscle groups through selective muscle exercise. Numerous studies had used the Kibler classification to guide scapular muscle exercises [37]. For example, patients with Kibler type I were typically characterized by weakness in the serratus anterior or lower trapezius muscles, while those with type III were marked by excessive tension in

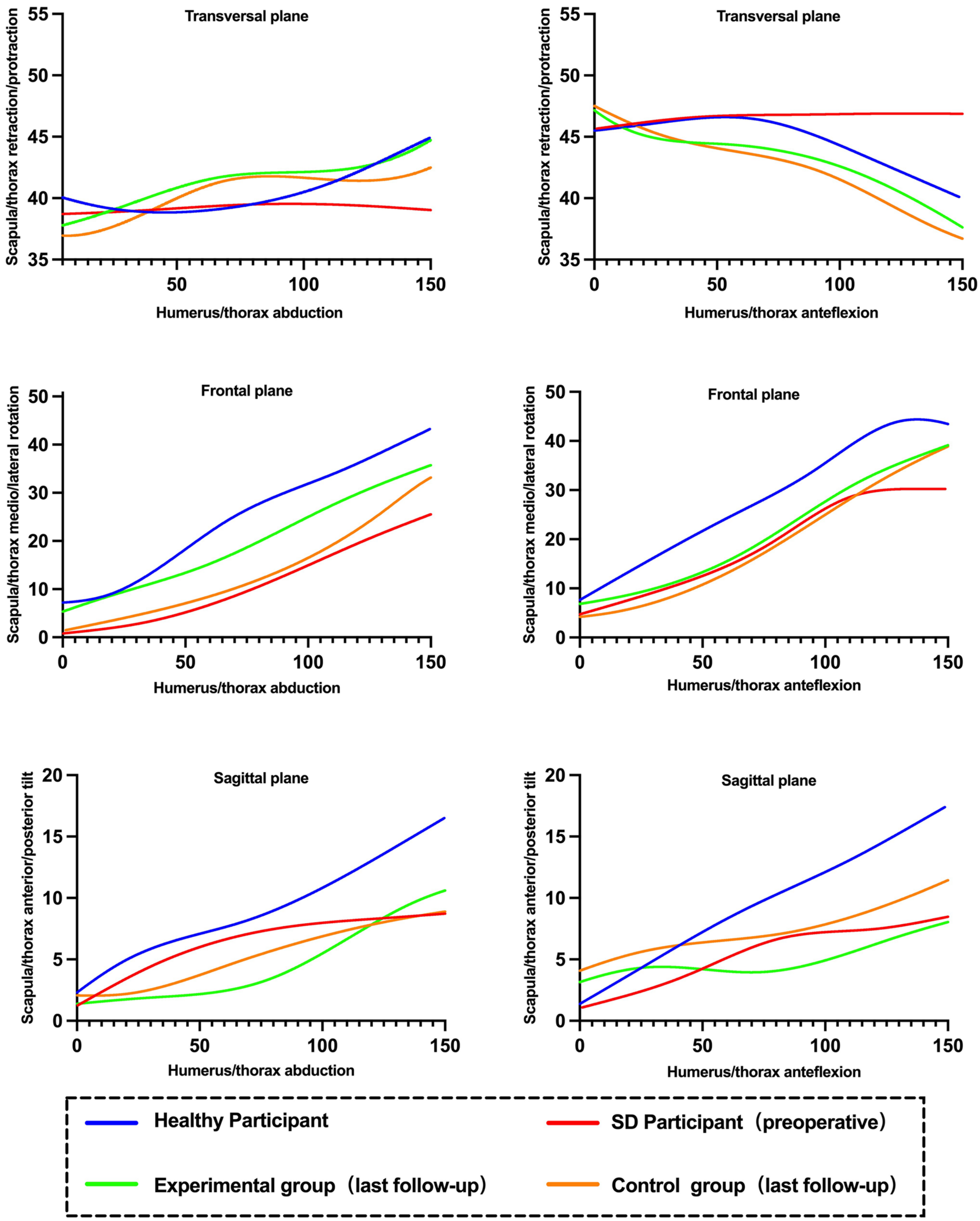


Fig. 3 Scapular kinematics of 60 SD patients in the experimental and control groups and 12 healthy participants during humeral forward anteflexion and abduction movement. The horizontal coordinate is the mobility of the shoulder joint, the vertical coordinate is the angle of change of the scapula, and the curves shown are the fitted curves of the position of the scapula at the corresponding joint mobility

the superior trapezius muscle [38]. The Kibler typology commonly used for scapular dyskinesis, described the static scapula's appearance and position but has limitations in guiding scapular exercises. The EMG results provided a basis for the development of an exercise program that reflected the dynamic scapular muscle movement status. Therefore, Kibler classification was not employed in this study; instead, patients in the study group underwent selective muscle exercise based on the EMG results. Our specialization was in increasing muscular strength and endurance in specific muscles or muscle groups. Flexibility of the soft tissues around the scapula is restored through a general rehabilitation program. The initial stage of rehabilitation focused on improving muscle control of shoulder movements, achieved through conscious muscle control exercises to enhance proprioceptive control, including relaxation and stabilization exercises. In addition, repetitive low-to-moderate level resistance exercises were added to the progressive rehabilitation program to optimize muscle activation [35, 39]. Throughout the rehabilitation period, extra attention was required as all patients were in the healing stage after rotator cuff repair surgery. We adopted an individualized feedback strategy to assess the patient's recovery status and adjust the rehabilitation exercise progress. An indicator that the surgeon needed to pay special attention to was the pain score, if the patient's pain escalated or became intolerable, we would reduce the frequency and strength requirements for exercise to ensure safety. We did not find meaningful differences in pain scores at the final outcome between the two groups. This is an acceptable result because performing additional rehabilitation exercises did not increase the patients' pain during the rehabilitation period.

Assessing 3D scapular kinematics was especially significant for patients with SD. The gold standard for assessing scapular kinematics is implanting multiple metal nails in the scapula and measuring it under X-ray fluorescence [40]. However, the invasive operation or biplane fluoroscopic method was not considered due to additional damage. A similar method of measurement using wireless inertial sensing devices was found to be acceptable, easy to perform, non-invasive, and allowed for the discovery of scapular trajectories [20, 41, 42]. However, due to the influence of the skin and muscles, the results were not always as accurate as direct observation of the bone structure. We minimized this error through measurement techniques, including higher sampling frequencies, multiple samples and the rich experience of the measurer. We measured scapular kinematics in 12 healthy individuals and used this as a criterion to assess scapular kinematics in patients with SD. We found that the range of motion of the scapula in preoperative SD patients was always lower than that of healthy individuals in both anteflexion and abduction activities, and that low scapular range of motion contributed less to the scapulohumeral rhythm and reflects the incoordination of the scapular muscle groups. After rotator cuff repair surgery, the range of motion of the scapula in SD patients significantly improved, and SD patients who received modified rehabilitation showed more significant improvements in gentle upward rotation and anterior tilt. At the last follow-up, the study group had better shoulder anteflexion and abduction range of motion than the control group, which might have benefited from an increase in upward rotation and anterior tilt range of motion.

This study had limitations: (1) This was a prospective, non-randomised controlled trial; a prospective, randomised controlled trial with more samples would have made the conclusions more convincing. Due to the propensity score matched design of the study, the potential aspect of bias, selection bias in patient recruitment, may affect the results. (2) This study only performed surface electromyography tests on preoperative patients in the experimental group, and the test results were used for selective exercise. We did not evaluate the electromyographic results of the control group and postoperative patients, but this would not affect our research conclusions. (3) Wireless surface EMG acquisition is less accurate and more susceptible to electromagnetic interference than intramuscular electrode acquisition signals. The quality of the recording may affect the accuracy of the EMG signal. (4) The use of wireless surface electromyography is not yet widespread in the clinic, which may affect the dissemination of our results. However, our study has provided clinicians with a viable approach. In future studies, we would try to use ergometers or other simple methods to tailor rehabilitation programmes for patients.

Conclusions

Patients with rotator cuff tears and scapular dyskinesis can achieve better shoulder mobility and scapular motion performance with an additional rehabilitation program after surgery. The improvements observed are relatively modest in clinical terms. Future studies with larger sample sizes and more refined assessment methods are warranted to further elucidate the true clinical significance and potential long-term benefits of such interventions.

Abbreviations

BMI	Body Mass Index
CMS	Constant-Murley Score
PCS	Physical Score
MCS	Mental Score
VAS	Visual Analogue Scale
ROM	Range of Motion
UT	Upper trapezius
MT	Middle trapezius
LT	Lower trapezius
SA	Serratus anterior
MVC	Maximal voluntary contraction

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Author contributions
SJN and ZYQ did the study and drafted the manuscript. ZQY and WRS were involved in the design, main contribution in literature search. MYR and CP were involved in the study design, and made further revision in this manuscript. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of The First Affiliated Hospital of Fujian Medical University. (Approval No.: MRCTA, ECFAH of FMU[2024]374). All procedures were conducted in accordance with the Declaration of Helsinki. All methods were carried out in accordance with relevant guidelines and regulations. Informed consent to participate was obtained from all of the participants in the study.

Consent for publication
All written informed consent for publication of identifying images or other personal or clinical details was obtained from all of the participants.

Competing interests
The authors declare no competing interests.

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