

Effects of Scapular-Focused and Kinetic Chain Exercise Programs on Shoulder Function in Athletes with Scapular Dyskinesia

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Effects of Scapular-Focused and Kinetic Chain Exercise Programs on Shoulder Function in Athletes with Scapular Dyskinesia

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Abstract

Background: Scapular dyskinesia is common in athletes, yet there is no consensus on the optimal rehabilitation approach. This study compared the effects of scapular-focused (SF) and kinetic-chain (KC) exercise programs on shoulder function in athletes with scapular dyskinesia.

Methods: Sixty-four athletes were randomly assigned to a KC group (n=21), a SF group (n=22), or a control group (n=21). Interventions were conducted over 6 weeks (3 sessions/week). Primary outcomes included isokinetic strength (internal/external rotation), shoulder joint proprioception, pain (VAS), and Disabilities of the Arm, Shoulder and Hand

(DASH) questioner. Data were analyzed using ANCOVA with baseline values as covariates, followed by Bonferroni post-hoc tests.

Results: Both intervention groups showed significant pre-to-post improvements in all outcomes ($P < 0.05$), while the control group showed no significant changes. ANCOVA revealed significant group effects for all measures ($P < 0.001$). KC training yielded superior improvements in internal rotation strength ($P < 0.001$). While both interventions significantly reduced pain and disability compared to the control ($P < 0.001$), SF exercises showed a greater efficacy in pain modulation, whereas KC exercises demonstrated broader benefits for functional performance. The difference between KC and SF groups regarding disability narrowly missed statistical significance ($P = 0.051$).

Conclusion: Both SF and KC exercises are effective, yet they address different clinical priorities. SF exercises are more effective for pain modulation and local scapular control, whereas KC exercises are superior for strength and functional gains. A sequential integration of both approaches is recommended for comprehensive athletic shoulder rehabilitation.

Trial Registration: This study was registered at <https://irct.behdasht.gov.ir/> with the registration number IRCT20250827067022N1 on 2025/09/22.

Keywords: Scapular dyskinesis; Kinetic chain; Rehabilitation; Athletes; Shoulder function; Proprioception.

Introduction

Despite substantial evidence supporting exercise therapy for shoulder dysfunction, a clear consensus regarding the most effective intervention for correcting scapular dyskinesis remains elusive [1, 2]. Previous studies have predominantly emphasized scapular-focused exercises (SF), framing them as a robust approach to enhancing neuromuscular control, correcting

muscle activation patterns, and restoring normal scapular kinematics [3–5]. These protocols are typically designed to facilitate the activation of the serratus anterior and lower trapezius while concurrently inhibiting the overactive upper trapezius, thereby optimizing scapular positioning and mobility during functional tasks [4, 5]. Enhanced function of these stabilizers theoretically contributes to improved scapulothoracic stability and scapulohumeral rhythm, ultimately attenuating shoulder pain and functional disability [6, 7].

Conversely, kinetic-chain (KC) approaches are predicated on the principle that upper-limb motion is the result of integrated coordination between the lower extremities, the core, and the shoulder girdle [8]. In this paradigm, the scapula functions as a critical link for force transmission between the trunk and the upper extremity [9–11]. Consequently, dysfunction anywhere along the kinetic chain can disrupt movement patterns, increase mechanical loading on shoulder structures, and precipitate pain or injury [12]. KC-based exercises, by prioritizing whole-body coordination, core stability, and efficient force transfer, are designed to improve functional performance and alleviate pathological stress on the shoulder complex [10, 12].

Notwithstanding the clinical significance of both strategies, there is a paucity of research directly comparing the efficacy of SF exercises versus KC-based training in athletes with scapular dyskinesis. Furthermore, most existing literature has focused on a limited subset of functional indices, often neglecting the simultaneous assessment of key outcomes such as shoulder muscle strength, joint proprioception, pain intensity, and functional disability [13, 14, 2, 15]. A more comprehensive evaluation of these variables is essential to gain a holistic understanding of the therapeutic impact of these interventions.

Athletes are particularly susceptible to shoulder dysfunctions, including scapular dyskinesis, due to the high-intensity, repetitive nature of their training [16]. This condition is known to alter shoulder kinematics [16], diminish muscular efficiency [17], impair joint proprioception,

and elevate the risk of secondary shoulder injuries [1]. Given these implications, identifying the most effective rehabilitation approach is of paramount importance. Therefore, the primary objective of this study was to compare the effects of SF training versus KC training on shoulder muscle strength, joint proprioception, pain intensity, and upper-limb functional disability in athletes with scapular dyskinesis.

Methods

Study Design

This study was a three-arm, parallel-group, randomized controlled trial (RCT) employing a pre-test/post-test design. Eligible participants were randomly allocated to one of three groups: SF exercise, KC exercise, or a control group. This randomized controlled trial was conducted and reported in accordance with the CONSORT 2010 Statement.

Participants

The study population comprised male athletes aged 18–30 years from Tehran and Alborz provinces, with at least three years of regular participation in overhead sports. Participants were diagnosed with scapular dyskinesis by a licensed physiotherapist (M.H., Medical Council No. F-2706). The diagnosis of scapular dyskinesis was based on clinical assessment, including observation of abnormal prominence of the scapular bony structures (inferior angle, medial border, or superior angle) and the Kibler lateral scapular slide test (LSST). The LSST involves measuring the distance between the medial border of the scapula and the thoracic spinous processes in various shoulder positions; significant inter-side asymmetry was considered indicative of dyskinesis [40]. Scapular dyskinesis classification was based on the dominant shoulder, corresponding to the primary sport-specific overhead limb. Dyskinesis was further classified into three primary patterns according to Kibler's classification: Type I, characterized

by prominence of the inferior angle of the scapula and commonly associated with weakness of the lower trapezius and serratus anterior muscles, which may contribute to subacromial impingement and pain during shoulder abduction; Type II, characterized by prominence of the medial border of the scapula, often related to weakness of the trapezius and rhomboid muscles and resulting in scapular winging; and Type III, characterized by excessive early elevation and superior rotation of the scapula, reflecting impaired control of scapular movement in the sagittal plane [18].

Based on a priori power analysis using G*Power software (version 3.1.7), with a significance level (α) of 0.05, statistical power ($1-\beta$) of 0.95, and an effect size of 0.40, the minimum required sample size was estimated to be 64 participants. To account for potential attrition, 68 participants were initially recruited. Ultimately, 64 participants completed the study and were randomly allocated to the SF exercise group (n=21), the KC exercise group (n=22), or the control group (n=21) (Figure 1).

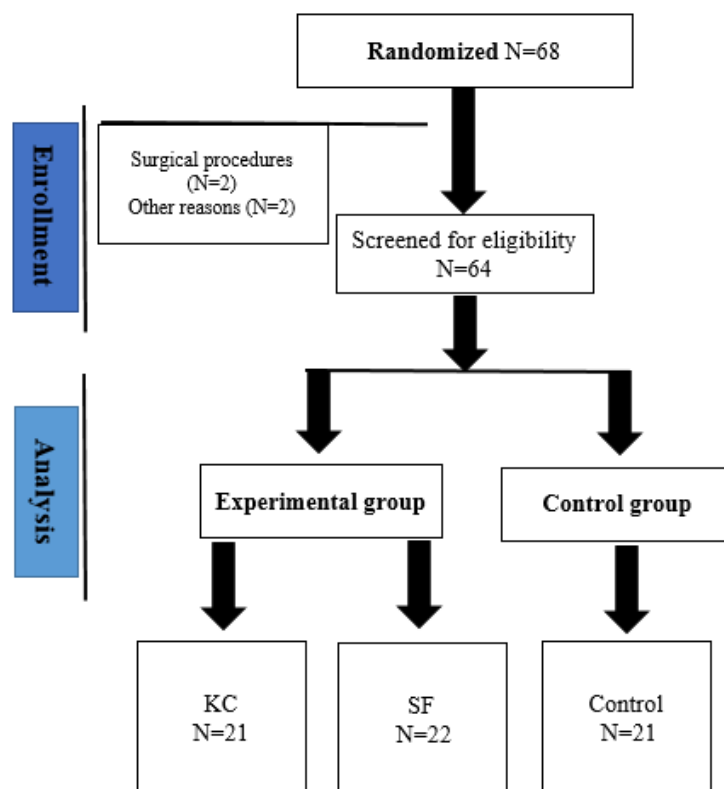


Figure 1. Characteristic of groups, Note: Kinetic-chain (KC), Scapula-Focused (SF).

Inclusion criteria were: age 18–30 years, male gender, a minimum of three years of regular sports activity, a positive LSST (Figure 2-d), and pain intensity scores between 3 and 7 on the Visual Analog Scale (VAS). Exclusion criteria included: unwillingness to continue the study, body mass index outside the normal range (18–25 kg/m²), history of shoulder trauma, fracture, or dislocation, presence of shoulder joint movement restriction, history of upper-limb surgery within the past two years, presence of structural abnormalities in the shoulder or spine (e.g., thoracic kyphosis or scoliosis), and any neurological or systemic musculoskeletal conditions affecting movement [19, 20].

Ethics approval and consent to participate

This research was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Kharazmi University (IR.KHU.REC.1404.066), and the study protocol was prospectively registered in the Iranian Registry of Clinical Trials (IRCT20250827067022N1). Prior to participation, the study's objectives and procedures were thoroughly explained to all participants, and written informed consent was obtained. Participants were assured of the confidentiality of their information and their right to withdraw at any stage without penalty.

Randomization and blinding

Following initial assessments and confirmation of eligibility, participants were randomly assigned to one of the three groups using a computer-generated random number sequence. To minimize allocation bias, the randomization sequence was prepared by a researcher uninvolved in the intervention or assessment phases. Due to the nature of the exercise interventions, blinding of participants and the exercise trainer was not feasible. However, the outcome assessor, responsible for measuring strength, proprioception, pain, and functional disability,

was blinded to group allocation. Furthermore, data analysis was performed by a statistician who was unaware of the group assignments to mitigate potential interpretation bias.

Outcome measures

The dependent variables assessed were shoulder internal and external rotation strength, shoulder joint proprioception, pain intensity, and upper-limb functional disability. Isokinetic strength of the shoulder internal and external rotator muscles was measured using the Biodex System III isokinetic dynamometer. Testing was performed at an angular velocity of 60°/s in the scapular plane (defined as 45° shoulder abduction, 30° shoulder horizontal flexion, and 90° elbow flexion). The mean of three maximal efforts was recorded as the measure of muscle strength (Figures 2-a, b) [21]. Joint proprioception was evaluated using the Active Joint Position Sense (AJPS) test with the Biodex system. Participants, with eyes closed, were asked to replicate target joint angles of 30° for internal and external rotation; the absolute angular error was calculated as the measure of proprioceptive acuity (Figure 2-c) [22]. Pain intensity was assessed using a 10-cm VAS, ranging from ‘no pain’ to ‘worst imaginable pain’, where participants marked their perceived pain level [23]. Functional upper-limb disability was measured using the DASH questionnaire, a 30-item measure assessing symptoms and functional activities, with scores ranging from 0 to 100 (higher scores indicating greater disability) [24].

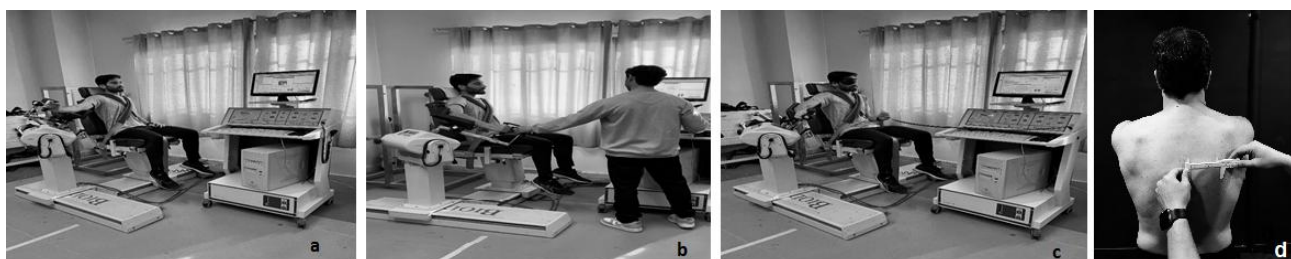


Figure 2. Assessment procedures: (a, b) Isokinetic strength measurement of internal and external rotators at 60°/s in the scapular plane (45° abduction, 30° horizontal flexion, and 90° elbow flexion); (c) Assessment of joint proprioception; (d) Kibler lateral scapular slide test.

Interventions

The exercise interventions were administered over a period of 6 weeks, three times per week on non-consecutive days, with each session lasting approximately 45 minutes (Figure 3). The scapular-focused exercise group performed a program comprising neuromuscular control exercises and strengthening of the scapular stabilizing muscles. Resistance intensity for strengthening exercises progressed from an initial 60% to 80% of one-repetition maximum (1RM) (Table 1) [25].



Figure 3. 1. Towel slide, 2. Scapula PNF, 3. Inferior glide, 4. Scapula clock, 5. Diagonal D1, 6. Push up plus, 7. Full can, 8. Prone horizontal abduction with external rotation, 9. Side-lying external rotation, 10. Scapula punch, and 11. Horizontal row

Table 1. Scapular-focused exercise protocol and progression.

Week	Type of Exercise	Exercise Name	Sets	Repetitions	Description / Intensity
1-2	Neuromuscular	Towel Slide / Scapula Clock	3	10	Motor control without weight
1-2	Strengthening	Push-up Plus / Full Can / Horizontal Rowing	3	10	60% of one-repetition maximum (1RM)
3-4	Neuromuscular	PNF Scapular / Towel Slide	3	12	Increased motor control accuracy

3-4	Strengthening	Scapular Punch / Diagonal D1 / Side-lying External Rotation	3	12	60–70% of one-repetition maximum (1RM)
5-6	Neuromuscular	Scapula Clock / Towel Slide	3	15	Advanced motor control
5-6	Strengthening	Diagonal D1 / Push-up Plus / Prone Horizontal Abduction with External Rotation	3	15	70–80% of one-repetition maximum (1RM)

The KC exercise group engaged in exercises emphasizing force transfer from the lower extremities to the upper extremities, involving coordinated activation of the lower limbs, trunk, and shoulder girdle (Figure 4). The control group maintained their usual physical activity levels and did not engage in any specific corrective exercise program during the study period (Table 2) [9, 26, 27, 28].

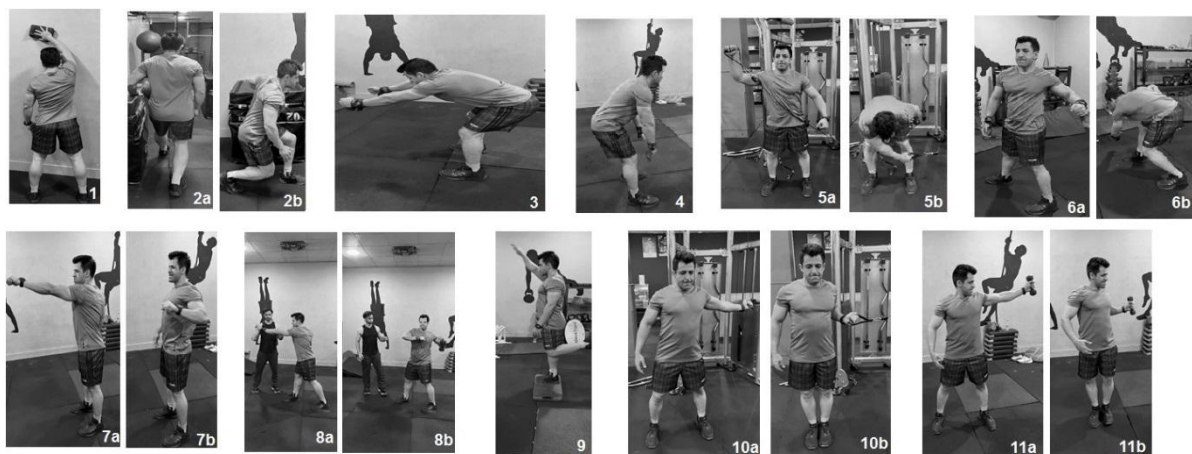


Figure 3. 1. Wall wash, 2. Low row, 3. Kinetic chain row, 4. Sternal lift, 5. External / internal diagonal rotation, 6. Short lever lawnmower, 7. Shoulder punch, 8. Power position, 9. Shoulder flexion with anterior step up, 10. Fencing, and 11. Lateral stride punch

Table 2. Kinetic-chain exercise protocol and progression

Week		Wall Wash	Low Row	Kinetic Chain Row	Sternal Lift	External/Internal Diagonal Rotation	Short Lever Lawnmower	Shoulder Punch	Power Position/ Step Back	Shoulder Flexion with Anterior Step Up	Fencing	Lateral Stride Punch
1	Session 1	4*10	4*10	4*10	4*10	4*10	4*10					
	Session 2	4*12	4*12	4*12	4*12	4*12	4*12					
	Session 3	5*10	5*10	5*10	5*10	5*10	5*10					
2	Session 1		4*10	4*10	4*10	4*10	4*10	4*10				
	Session 2		4*12	4*12	4*12	4*12	4*12	4*12				
	Session 3		5*10	5*10	5*10	5*10	5*10	5*10				
3	Session 1			4*10	4*10	4*10	4*10	4*10	4*10			
	Session 2			4*12	4*12	4*12	4*12	4*12	4*12			
	Session 3			5*10	5*10	5*10	5*10	5*10	5*10			

4	Session 1				4*10	4*10	4*10	4*10	4*10	4*10		
	Session 2				4*12	4*12	4*12	4*12	4*12	4*12		
	Session 3				5*10	5*10	5*10	5*10	5*10	5*10		
5	Session 1					4*10	4*10	4*10	4*10	4*10	4*10	
	Session 2					4*12	4*12	4*12	4*12	4*12	4*12	
	Session 3					5*10	5*10	5*10	5*10	5*10	5*10	
6	Session 1						4*10	4*10	4*10	4*10	4*10	4*10
	Session 2						4*12	4*12	4*12	4*12	4*12	4*12
	Session 3						5*10	5*10	5*10	5*10	5*10	5*10

Procedure

Participants were recruited through advertisements in sports clubs across Tehran and Alborz provinces. Following screening for eligibility criteria and completion of informed consent forms, all participants underwent baseline assessments (pre-test). These assessments included shoulder strength and proprioception using the Biodex system, as well as pain intensity and functional disability measured via VAS and the DASH questionnaire, respectively. Post-intervention assessments were conducted under identical conditions after the completion of the 6-week intervention period. All testing procedures were carried out in the Human Movement and Biomechanics Laboratory, Faculty of Physical Education and Sport Sciences, Kharazmi University.

Statistical analysis

Data analysis was performed using SPSS software (version 24). Descriptive statistics are presented as mean $\pm$ standard deviation (SD). The normality of data distribution was assessed using the Kolmogorov–Smirnov test, and homogeneity of variances was checked with Levene’s test. Analysis of Covariance (ANCOVA) was used to compare between-group differences in post-test outcomes while controlling for pre-test values. Paired t-tests were employed to assess within-group changes from pre-test to post-test. A significance level of $p < 0.05$ was adopted for all analyses.

Results

Sixty-four athletes with scapular dyskinesis were included (KC: $n=21$; SF: $n=22$; CON: $n=21$). Baseline demographic variables did not differ significantly among groups (Table 1; $P > 0.05$).

TABLE 3. MEAN AND STANDARD DEVIATION OF PARTICIPANTS' CHARACTERISTICS (MEAN $\pm$ SD)

Variables	Kinetic Chain Training Group (n=21)	Scapular-Focused Training Group (n=22)	Control Group (n=21)	P value
Height (cm)	180.38 $\pm$ 6.57	180.55 $\pm$ 6.06	180.43 $\pm$ 5.36	0.966
Weight (kg)	73.43 $\pm$ 5.98	74.14 $\pm$ 5.57	74.14 $\pm$ 5.55	0.896
Age (years)	20.62 $\pm$ 1.11	20.45 $\pm$ 1.05	20.62 $\pm$ 1.07	0.847
BMI (kg/m ²)	22.55 $\pm$ 1.08	22.73 $\pm$ 1.13	22.72 $\pm$ 1.15	0.850

All variables were normally distributed (Kolmogorov–Smirnov, $P > 0.05$) and homogeneity of variances was confirmed (Levene's test, $P > 0.05$), supporting the use of parametric analyses.

Paired t-tests showed significant pre-to-post improvements in both intervention groups (KC and SF) for strength, proprioception, pain, and disability (Table 4; $P < 0.05$). No significant changes were observed in the control group ($P > 0.05$).

Table 4. Within-Group Comparisons Between Pre-test and Post-test. Note: Internal (I), External (E), Kinetic Chain (KC), and Scapula focused (SF).

Variable	KC (N = 21)			SF (N = 22)			Control (N = 21)		
	Pre-test	Post-test	P-value	Pre-test	Post-test	P-value	Pre-test	Post-test	P-value
Strength (I)	41.23 $\pm$ 13.3	49.81 $\pm$ 13.9	0.001	41.33 $\pm$ 7.64	45.92 $\pm$ 7.15	0.001	35.83 $\pm$ 11.8	33.85 $\pm$ 10.41	0.659
Strength (E)	29.54 $\pm$ 4.24	34.66 $\pm$ 7.05	0.001	29.09 $\pm$ 6.09	31.65 $\pm$ 7.82	0.02	28.23 $\pm$ 4.88	26.87 $\pm$ 4.21	0.269
Proprioception (I)	5.18 $\pm$ 2.04	3.27 $\pm$ 2.04	0.001	6.01 $\pm$ 2.88	4.17 $\pm$ 2.52	0.001	6.75 $\pm$ 3.49	7.41 $\pm$ 3.49	0.161
Proprioception (E)	6.12 $\pm$ 3.46	3.44 $\pm$ 2.43	0.001	5.78 $\pm$ 2.41	3.38 $\pm$ 1.43	0.001	6.04 $\pm$ 3.19	6.89 $\pm$ 2.80	0.439
Pain	5.95 $\pm$ 1.20	4.10 $\pm$ 0.83	0.001	6.05 $\pm$ 1.13	3.95 $\pm$ 0.80	0.001	5.71 $\pm$ 1.10	5.28 $\pm$ 1.07	0.096

Disability	58.90 ± 7.28	48.04 ± 6.35	0.001	58.98 ± 8.08	51.18 ± 7.72	0.001	55.26 ± 7.69	54.81 ± 8.04	0.190
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Paired t-tests showed significant pre-to-post improvements in both intervention groups (KC and SF) for strength, proprioception, pain, and disability ($P < 0.05$), whereas no significant changes were observed in the control group ($P > 0.05$) (Table 5).

Table 5. Homogeneity of variances (Levene's test) and ANCOVA results comparing post-test scores across study groups. Note: Internal (I), and External (E).

Variable	df ₁ -df ₂	P-value	Levene Statistic	F	P-value	Effect Size (Partial η^2)
Strength (I)	2-6	0.078	2.660	23.62	0.001	0.458
Strength (E)	2-6	0.062	2.920	7.94	0.001	0.221
Proprioception (I)	2-6	0.054	3.060	22.64	0.001	0.447
Proprioception (E)	2-6	0.140	2.028	24.20	0.001	0.464
Pain	2-6	0.977	0.023	16.35	0.001	0.369
Disability	2-6	0.919	0.085	33.32	0.001	0.543

Bonferroni-adjusted pairwise comparisons indicated that both training groups improved significantly more than the control group across outcomes (Table 6; $P < 0.05$). KC achieved greater gains than SF in internal rotation strength ($P < 0.001$), while KC and SF did not differ significantly for external rotation strength, proprioception, or pain ($P > 0.05$). For disability, the KC–SF difference narrowly missed statistical significance ($P = 0.051$) (Table 6).

Table 6. Bonferroni Pairwise Comparisons Between Groups. Note: Internal (I), External (E), Kinetic Chain (KC), and Scapula focused (SF).

Variable	Comparison	Comparison	P-value
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		Mean Difference	
Strength (I)	KC vs SF	4.439	0.001
	KC vs Control	8.869	0.001
	SF vs Control	4.430	0.004
Strength (E)	KC vs SF	2.681	0.273
	KCh vs Control	6.503	0.001
	SF vs Control	3.822	0.068
Proprioception (I)	KC vs SF	-0.239	1.000
	KC vs Control	-2.553	0.001
	SF vs Control	-2.323	0.001
Proprioception (E)	KC vs SF	-0.241	1.000
	KC vs Control	-3.235	0.001
	SF vs Control	-2.994	0.001
Pain	KC vs SF	0.184	1.000
	KC vs Control	-1.296	0.001
	SF vs Control	-1.480	0.001
Disability	KC vs SF	-2.830	0.051
	KC vs Control	-9.780	0.001
	SF vs Control	-6.950	0.001

No adverse events, harms, or unintended effects related to the exercise interventions were observed or reported during the study.

Discussion

This study aimed to compare the effects of SF and KC exercise programs on shoulder strength, proprioception, pain, and functional disability in athletes with scapular dyskinesis. Both interventions yielded significant improvements in all clinical outcomes compared to the control

group. However, our findings revealed distinct intervention-specific responses: KC exercises appeared superior in enhancing muscle strength and proprioception, whereas SF exercises demonstrated a greater capacity for pain reduction. These findings suggest that the two approaches operate through distinct mechanistic pathways and may serve complementary roles across different phases of rehabilitation.

The superior strength gains observed in the KC group can be interpreted through the kinetic-chain integration paradigm. Functional shoulder performance is inherently dependent on the inter-segmental coordination of the entire kinetic chain, where force generation initiates in the lower extremities and is transferred through the trunk to the upper limb [12]. KC exercises improve core stability and neuromuscular coordination, facilitating more efficient energy transfer and enhanced glenohumeral force production [13, 29, 2]. Furthermore, these exercises may optimize muscle co-contraction, thereby improving dynamic joint stability [30]. Our results align with recent evidence suggesting that KC training mitigates compensatory movement patterns and refines neuromuscular synergy in athletes [13,31].

Regarding proprioception, both interventions successfully reduced joint position sense errors, with greater improvements noted in the KC group. Proprioception is critical for neuromuscular control, relying on mechanoreceptors within muscles, tendons, and joint capsules to relay afferent data to the central nervous system [32]. In athletes with scapular dyskinesis, altered scapulohumeral rhythm often impairs motor control precision. Our findings corroborate previous research demonstrating that corrective exercises enhance proprioceptive acuity [2-4, 33,34]. The pronounced effect of KC exercises may stem from a more robust sensorimotor stimulus, whereas SF training likely improves local joint control by optimizing scapular positioning [35].

Regarding pain management, SF exercises demonstrated superior efficacy. This aligns with existing literature emphasizing the role of scapular stabilization in reducing shoulder pain [5, 9, 36, 37, 38]. Biomechanically, pain in scapular dyskinesis is often linked to scapulohumeral rhythm disruption and subsequent subacromial impingement [39]. By strengthening the serratus anterior and lower trapezius, SF exercises effectively restore scapular kinematics and alleviate pressure on pain-sensitive structures [16, 40].

Concerning functional disability, both programs significantly improved DASH scores; however, the KC approach provided superior functional outcomes. This supports the notion that functional upper limb performance is largely dictated by the efficiency of the entire kinetic chain [6, 9, 41, 42].

From a clinical perspective, these results suggest that exercise selection should be phase-dependent. SF exercises may be prioritized in the early stages of rehabilitation to address pain and scapular positioning, while KC exercises are more suitable for advanced stages to maximize power, proprioception, and functional performance. A sequential integration of both strategies may offer the most effective framework for the safe return-to-sport of athletes [11, 42, 43].

Despite these findings, several limitations must be acknowledged. The intervention period was relatively short, and long-term follow-up was not conducted. Furthermore, the cohort was restricted to a specific athletic population, and advanced objective measures—such as electromyography or three-dimensional motion analysis—were not employed. Future research should include larger, more diverse samples with long-term follow-up and advanced motion analysis to further elucidate the underlying neuromuscular mechanisms.

Conclusion

Both scapular-focused and kinetic-chain exercises are effective in improving shoulder function in athletes with scapular dyskinesis, yet they address different clinical priorities. While SF exercises are more effective in pain modulation and local scapular control, KC exercises provide superior gains in strength, proprioception, and functional performance. A targeted, phase-based combination of these two approaches represents an optimal strategy for developing comprehensive rehabilitation programs.

Declarations

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Author contributions

N.T. contributed to data collection, literature review, data classification, methodology, statistical analysis, and manuscript preparation. S.S. contributed to supervision, methodology, conceptualization, and critical revision of the manuscript. M.H. contributed to study conception, study design, manuscript writing, and conceptualization. B.J. contributed to research guidance and monitoring of the study process. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. The data are not publicly available due to privacy and ethical restrictions related to participant confidentiality.

Ethics approval and consent to participate

This single-blind, single-center, prospective randomized controlled trial was approved by the Ethics Committee of Kharazmi University (Approval ID: IR.KHU.REC.1404.066). The study was conducted at the Faculty of Physical Education and Sport Sciences, Kharazmi University, Tehran, Iran. All procedures were performed in accordance with the ethical principles of the Declaration of Helsinki (2013 revision). The trial was prospectively registered in the Iranian Registry of Clinical Trials (IRCT) under the registration number IRCT20250827067022N1. Written informed consent was obtained from all participants prior to enrollment. All intervention sessions were supervised by a licensed physiotherapist to ensure participant safety, protocol fidelity, and compliance with institutional ethical standards.

Consent for publication

Written informed consent for publication of personal and/or clinical details and any identifying images was obtained from all participants (or their legal guardians).

Competing interests

The authors declare that they have no competing interests.

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