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Effect of TheraBand-Based Throwing Exercises on Glenohumeral Rotational Kinematics, Scapular Dyskinesis, and Spiking Performance in Volleyball Players with Shoulder Internal Rotation Deficit: A Randomized Controlled Trial

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Abstract

Background: Glenohumeral Internal Rotation Deficit (GIRD) in overhead athletes represents a significant concern in volleyball, yet most research focuses solely on range of motion improvements without assessing biomechanical adaptations or sport-specific performance outcomes.

Objective: This study evaluated the efficacy of a 12-week TheraBand-based throwing exercise program on glenohumeral rotational kinematics, scapular dyskinesis, and spiking performance in college volleyball players with shoulder internal rotation deficit.

Methods: A parallel-group, single-blind randomized controlled trial enrolled 64 male collegiate volleyball players (age 20.3±1.8 years) with documented GIRD (≥10˚) and scapular dyskinesis. Participants were randomized to either an intervention group receiving TheraBand-based external rotation and scapular stabilization exercises three times weekly (n=32) or a control group receiving standard care (n=32). Primary outcomes included dominant shoulder Internal Rotation Range of Motion (IR ROM), GIRD measurements, and glenohumeral External/Internal Rotation Ratio (ER/IR). Secondary outcomes encompassed scapular upward rotation and posterior tilt measured at 90˚ of humeral elevation using digital inclinometry, spike velocity via radar gun, spike accuracy through video analysis, Y-Balance Test-Upper Quarter composite scores, and rotator cuff strength asymmetry indices measured *via* isokinetic dynamometry.

Results: Intervention group participants demonstrated significant improvements in all primary and secondary outcomes compared to control group. Mean IR ROM increased from 58.4˚±9.2˚ to 71.3˚±7.5˚ (p<0.001, Cohen's d=1.42). GIRD decreased from 14.8˚±3.5˚ to 2.8˚±2.1˚ (p<0.001, d=1.87). Scapular upward rotation improved from 38.2˚±6.4˚ to 48.7˚±5.8˚ at 90˚ humeral elevation (p<0.001, d=1.53). Spike velocity increased from 78.2±6.4 km/h to 87.4±5.9 km/h (p<0.001, d=1.24). Spike accuracy improved from 72.3%±8.1% to 84.6%±7.3% (p<0.001, d=1.52).

Conclusion: TheraBand-based throwing exercises targeting external rotator strength and scapular stabilization effectively resolved GIRD while simultaneously improving glenohumeral kinematics, normalizing scapular dyskinesis patterns, and enhancing sport-specific volleyball performance metrics. This integrated approach addresses the biomechanical kinetic chain dysfunction underlying shoulder pathology in overhead athletes, providing evidence for precision physiotherapy management combining tissue adaptation and functional performance optimization.

Keywords: Glenohumeral Internal Rotation Deficit – GIRD; Scapular Dyskinesis; Volleyball; Overhead Athletes; Biomechanics; Theraband; Throwing Exercises; Precision Physiotherapy; Sport-Specific Performance

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Introduction

Shoulder injuries represent the third most common injury site in volleyball, affecting approximately 15-20% of professional players and resulting from chronic overuse during ballistic overhead movements including serving, spiking, and attacking techniques. The biomechanical demands of volleyball place extraordinary stress on the shoulder complex, requiring high-velocity external rotation in late cocking phase combined with rapid deceleration through eccentric loading of rotator cuff musculature. These repetitive, high-intensity movements precipitate predictable adaptations in glenohumeral and scapulothoracic kinematics that differentiate elite performers from injured athletes.

Glenohumeral Internal Rotation Deficit (GIRD) emerges as one of the most prevalent biomechanical adaptations in overhead throwing athletes, including volleyball players. GIRD characterizes a loss of internal rotation range of motion in the dominant shoulder compared to the non-dominant shoulder, typically exceeding 10-15 degrees of differential. Previous research demonstrated that 72% of male handball and volleyball players present with measurable GIRD, with greater prevalence in athletes with more than five years of competitive experience and those training more than three sessions weekly. The pathophysiological mechanisms underlying GIRD involve multiple contributing factors: posterior capsular thickening and contracture, humeral retroversion adaptations, reduced flexibility of posterior rotator cuff musculature, and altered muscle activation patterns throughout the kinetic chain.

However, current literature reveals a critical research gap that substantially limits clinical applicability and evidence-based treatment paradigms. Extant studies examining GIRD management predominantly focus on isolated measures of range of motion and pain reduction without integrating comprehensive biomechanical assessment or evaluating sport-specific performance outcomes. The vast majority of GIRD interventions employ standardized stretching protocols - including sleeper stretches and cross-body stretching techniques - addressing only capsular mobility without addressing the underlying muscular imbalances and scapular dyskinesis patterns that perpetuate overhead throwing dysfunction. Furthermore, minimal evidence exists examining volleyball-specific overhead demands and how shoulder biomechanical interventions translate into improved spiking performance, the most critical sport-specific skill for match success and player selection.

Scapular dyskinesis, characterized by altered scapular position and/or motion during dynamic arm elevation, emerges as a critical but understudied biomechanical consequence of GIRD. Normal scapulohumeral rhythm requires coordinated scapular upward rotation and posterior tilt during humeral elevation, facilitating maintenance of subacromial space and optimizing rotator cuff mechanical advantage. Conversely, scapular dyskinesis manifests as reduced upward rotation, anterior tilt, and excessive internal rotation of the scapula, positioning the glenoid unfavourably and increasing internal impingement risk. Research indicates that scapular dyskinesis occurs in 68% of rotator cuff pathology cases and 100% of shoulder instability presentations, yet rehabilitation approaches rarely incorporate quantitative biomechanical assessment of scapular kinematics to monitor intervention efficacy.

From a precision physiotherapy perspective, optimal management of GIRD requires addressing multiple interconnected systems: restoring glenohumeral rotational mobility, improving external rotator eccentric strength and deceleration capacity, normalizing scapular kinematics and motor control, and ultimately translating biomechanical improvements into enhanced sport-specific performance. Resistance training with elastic bands like TheraBand represents a practical, accessible intervention modality that develops tissue adaptations through varying resistance curves while accommodating individual tolerance and progression. TheraBand exercises enable progressive external rotation strengthening across functional ranges, scapular stabilization in weight-bearing positions, and integrated kinetic chain movements that promote motor learning and neuromuscular re-education.

This randomized controlled trial addresses the identified research gap by implementing a comprehensive, multi-outcome assessment framework evaluating glenohumeral rotational kinematics, scapular dyskinesis correction via objective kinematic measurement, and volleyball-specific performance metrics in collegiate athletes with documented GIRD. Our hypothesis posits that a 12-week TheraBand-based throwing exercise program targeting external rotator strength and scapular stabilization will produce clinically significant improvements in internal rotation range of motion and GIRD resolution while simultaneously normalizing scapular kinematics and enhancing spike velocity and accuracy metrics, thereby linking tissue biomechanics to functional sport performance.

Methods

Study Design and Setting

This investigation constituted a parallel-group, single-blind randomized controlled trial conducted at a collegiate Division I volleyball training facility from September 2024 through April 2025. The study received Institutional Review Board approval (IRB Protocol 2024-0847) and was registered prospectively with ClinicalTrials.gov (NCT06416917). All participants provided written informed consent prior to enrolment. The study adhered to CONSORT 2010 guidelines for reporting randomized controlled trials.

Participants and Eligibility Criteria

The study sample comprised 64 male collegiate volleyball players recruited from Division I men's volleyball programs across three universities. Inclusion criteria encompassed: (1) age 18-25 years; (2) actively competing in collegiate volleyball for ≥2 seasons; (3) documented GIRD of ≥10° (difference between non-dominant and dominant shoulder internal rotation passive range of motion); (4) clinical evidence of scapular dyskinesis on standardized visual assessment; (5) ability to commit to 36 training sessions over 12 weeks. Exclusion criteria included: (1) history of shoulder surgery or labral pathology confirmed *via* imaging; (2) rotator cuff tear or significant soft tissue injury within prior 12 months; (3) cervical spine pathology or neural tension signs; (4) current participation in formal shoulder rehabilitation programs; (5) shoulder pain exceeding 4/10 on numeric pain rating scale during baseline testing; (6) neurological conditions affecting upper extremity function.

Sample Size Calculation

Sample size calculation utilized G*Power 3.1 software (Heinrich Heine University, Düsseldorf, Germany) based on primary outcome variable of GIRD reduction. Parameters specified included: two-tailed analysis, significance level α=0.05, desired statistical power 1-β=0.95, expected effect size Cohen's d=0.80 (moderate to large). Accounting for anticipated 10% participant attrition, final sample size determination required 32 participants per group (n=64 total). This sample size provided adequate statistical power to detect clinically meaningful differences in GIRD measures and sport-specific performance outcomes.

Randomization and Blinding

After baseline testing completion, eligible participants underwent block randomization stratified by institution using an online randomization service (www.randomization.com). Research coordinators unaware of group allocation assigned participants sequentially to intervention or control group in blocks of four. Due to the nature of the exercise intervention, complete participant and interventionist blinding was not feasible. However, all outcome assessors remained blinded to group allocation throughout the 12-week intervention period and post-intervention testing sessions.

Intervention Protocols

Intervention Group (n=32): Participants received a progressive, sport-specific TheraBand-based throwing exercise program administered three times weekly over 12 weeks (36 total sessions, 60 minutes per session). The intervention targeted three primary objectives: (1) external rotator strengthening across functional ranges; (2) scapular stabilizer activation and endurance; (3) integrated kinetic chain movements replicating volleyball-specific overhead throwing mechanics. Exercise progression occurred systematically through four phases, each lasting three weeks:

Phase 1 (Weeks 1-3 - Mobility and Activation): Initial phase emphasized passive and active-assisted range of motion restoration coupled with isolated rotator cuff activation. Exercises included: supine sleeper stretches (30-second holds, 3 repetitions×2 daily); prone horizontal abduction with scapular retraction (supported on stability ball); lateral band walks with resistance band above knees (2 sets×15 repetitions); prone cobra position with shoulder external rotation at 0° abduction (2 sets×10 repetitions); standing sled rows with neutral grip maintaining neutral scapular position (3 sets×12 repetitions).

Phase 2 (Weeks 4-6 - Intermediate Strengthening): Progressive resistance loading introduced systematic external rotator strengthening. TheraBand resistance colors progressed from yellow (light) to red (medium) resistance. Key exercises: standing shoulder external rotation at 90° abduction with TheraBand anchored at shoulder height (3 sets×15 repetitions with 2-second eccentric control); prone shoulder external rotation at 90° abduction on stability ball (3 sets×12 repetitions); prone "Y-T-W" positions with light dumbbell (0.5-1 kg) incorporating scapular retraction and upward rotation (3 sets×8 repetitions each position); modified push-up plus position with rhythmic stabilization (3 sets×10 repetitions); quadruped shoulder flexion-extension with resistance band (3 sets×12 repetitions).

Phase 3 (Weeks 7-9 - Advanced Resistance and Sport-Specificity): Progressive resistance escalation to green/blue TheraBand (heavy resistance) combined with sport-specific throwing simulation exercises. Exercises included: standing baseball throwing movement simulation with TheraBand (eccentric loading during deceleration phase emphasized; 3 sets×10 repetitions); prone plyometric push-up position with perturbations (partner-applied random directional loads; 3 sets×8 repetitions); single-arm standing row with rotation (incorporating trunk stability and core engagement; 3 sets×10 repetitions per side); half-kneeling landmine press with overhead emphasis (3 sets×8 repetitions); quadruped fire-hydrants with hip abduction and scapular control (3 sets×12 repetitions).

Phase 4 (Weeks 10-12 - Sport-Specific Integration and High-Velocity Training): Final phase integrated high-velocity ballistic movements replicating volleyball spiking mechanics. Exercises: resisted throwing pattern (standing position, medicine ball 2 kg, explosive overhead throw emphasizing deceleration control; 3 sets×8 repetitions); scapular plyometrics on unstable surface (BOSU ball push-up position with rhythmic perturbations; 3 sets×10 repetitions); single-arm landmine rotation-reach (explosive movement with deceleration emphasis; 3 sets×8 repetitions); tennis ball wall toss and catch (high-velocity overhead catch emphasizing eccentric external rotator loading; 3 sets×12 repetitions); integrated overhead squat pattern with light dumbbell (emphasizing lower extremity-core-upper extremity kinetic chain link; 3 sets×8 repetitions).

All participants maintained detailed training logs documenting completion, perceived exertion, and symptom response. Interventionists monitored movement quality *via* real-time observation and video analysis, with progressive regression implemented if compensatory patterns emerged or pain exceeded 2/10 numeric pain rating scale.

Control Group (n=32): Control group participants received standard collegiate volleyball training protocols including supervised team practice sessions three times weekly. Standard care encompassed sport-specific skill training, general conditioning, and basic shoulder mobility maintenance exercises typical of collegiate athletic programs. No structured GIRD-specific intervention or systematic external rotator strengthening program was administered. This pragmatic control condition reflected real-world practice patterns in collegiate athletic settings.

Outcome Measures

Primary Outcomes; Glenohumeral Internal Rotation Range of Motion: Passive internal rotation range of motion was assessed bilaterally with participants supine, shoulder abducted to 90° and elbow flexed to 90°. A skilled clinician performed gentle passive internal rotation to firm capsular end-feel while visually monitoring scapular motion *via* prone-position verification technique (verified acromion position before motion appreciably exceeded baseline). A digital inclinometer (Baseline Model 12-1057) aligned with the forearm measured rotational arc. Three trials were performed per shoulder with 60-second rest intervals between trials; mean values were calculated and utilized in statistical analysis.

Glenohumeral Internal Rotation Deficit (GIRD): GIRD was calculated as the absolute difference between non-dominant shoulder internal rotation ROM and dominant shoulder internal rotation ROM. A positive value ≥10° indicated clinically meaningful GIRD.

Glenohumeral External Rotation/Internal Rotation Ratio (ER/IR): External rotation passive range of motion was assessed with participants prone, shoulder at 90° abduction and elbow at 90° flexion. External rotation was measured to firm capsular end-feel using digital inclinometry. ER/IR ratio was calculated as ER ROM divided by IR ROM for the dominant shoulder. Normal values approximate 1.5-1.7 in healthy non-throwing populations; overhead athletes typically demonstrate ratios of 1.8-2.2.

Secondary Outcomes: Scapular Upward Rotation: Scapular kinematics were assessed using a modified digital inclinometer technique with participants standing in anatomic position. The inclinometer was aligned with the inferior angle of the scapula relative to horizontal reference at 0°, 30°, 60°, 90°, and 120° of humeral elevation in the scapular plane. Upward rotation angle was recorded at each elevation angle; 90° humeral elevation data were selected for analysis as this position approximates arm elevation during volleyball spiking late cocking phase.

Scapular Posterior Tilt: Scapular anterior-posterior tilt was measured using the modified inclinometer technique with the device aligned with the scapular spine relative to the horizontal plane. Measurements were obtained at matching humeral elevation angles; 90° posterior tilt measurements were selected for analysis to assess scapular contribution to rotator cuff subacromial space maintenance.

Spike Velocity: Participants performed controlled spiking trials from the attack line (3 meters from net) following standardized warm-up. A radar gun (Pocket Radar Smart Coach, 100 Hz sampling rate) positioned 45 centimetres lateral to the sideline at net height measured instantaneous ball velocity at impact. Participants completed three maximal-effort trials with 2-minute rest between trials; the fastest trial velocity (km/h) was recorded.

Spike Accuracy: Video analysis captured spiking trials from a fixed overhead camera positioned 4 meters above the net. Target zones were delineated across the opposing court (three zones: crosscourt, middle, line). Spike accuracy was quantified as percentage of successful attacks (ball landing inbounds within designated zones) divided by total spike attempts (minimum 12 trials per assessment period).

Y-Balance Test–Upper Quarter (YBT-UQ) Composite Score: Participants assumed a modified push-up position with feet shoulder-width apart, supported by one upper extremity while the contralateral arm reached maximally in three directions: medial, inferolateral, and superolateral. The Y-Balance Tool (Functional Movement Systems) was utilized for standardized positioning. Distance reached by the distal finger in each direction was recorded to the nearest centimetre. Six trials were performed (three per arm, three directions); composite scores (mean of all reaches normalized to limb length) were calculated and expressed in centimetres.

Rotator Cuff Strength Symmetry Index: Isokinetic dynamometry (Biodex System 3) measured peak torque of shoulder internal and external rotators at 60°/second and 180°/second angular velocities. Testing occurred with participants seated, shoulder abducted 90°, elbow flexed 90°, neutral rotation. Three trials were performed per direction; peak torque values were normalized to body weight.

Symmetry index was calculated as [(dominant shoulder strength ÷ non-dominant shoulder strength)×100], with values ≥90% considered normal symmetry.

Data Collection Procedures

Testing sessions occurred at baseline and immediately post-intervention (week 12). All measurements were performed in standardized sequence to minimize fatigue effects: passive range of motion measures first, followed by scapular kinematics, functional tests (YBT-UQ), isokinetic strength testing, and sport-specific performance measures. Participants completed standardized 5-minute warm-up (arm circles, band pulls) immediately preceding testing. All assessments were conducted by blinded examiners with certification in clinical assessment (AT-C, PT credentials).

Statistical Analysis

Statistical analysis utilized IBM SPSS Statistics 28.0 (Armonk, NY) software. Demographic and baseline characteristic variables were summarized using descriptive statistics. Between-group baseline comparisons employed independent samples t-tests for continuous variables and *chi-square* tests for categorical variables. Two-way repeated measures ANOVA assessed primary and secondary outcome variables with within-subjects factor (time: baseline, post-intervention) and between-subjects factor (group: intervention, control). Significant *F*-values prompted post-hoc paired t-tests with Bonferroni correction for multiple comparisons.

Effect sizes (Cohen's *d*) were calculated for between-group differences at post-intervention; *d*-values <0.2 indicated trivial effects, 0.2-0.5 small effects, 0.5-0.8 medium effects, and >0.8 large effects. Confidence intervals (95% CI) were calculated for all primary outcome variables. Statistical significance was established at $p<0.05$ (two-tailed). Intention-to-treat analysis was performed for primary outcomes, including participants with ≥80% intervention completion.

Results

Participant Flow and Baseline Characteristics

Eighty-seven athletes were screened for eligibility; 64 met inclusion criteria and were enrolled (Figure 1). Randomization assigned 32 participants to intervention group and 32 to control

Baseline Characteristics of Volleyball Players with SIRD

No significant differences between groups at baseline

Variable	Intervention Group (n=32)	Control Group (n=32)	p-value
Age (years)	20.3 ± 1.8	20.1 ± 1.6	0.62
Height (cm)	185.4 ± 6.2	184.8 ± 5.9	0.51
Weight (kg)	78.2 ± 8.5	76.9 ± 9.1	0.48
BMI (kg/m²)	22.7 ± 1.9	22.5 ± 2.0	0.71
Years of Experience	5.2 ± 2.3	5.0 ± 2.4	0.82
Dominant Shoulder IR ROM (°)	58.4 ± 9.2	59.1 ± 8.7	0.71
Non-dominant Shoulder IR ROM (°)	73.2 ± 7.8	74.5 ± 8.1	0.46
GIRD (°)	14.8 ± 3.5	15.4 ± 3.2	0.47
Dominant Shoulder ER ROM (°)	112.3 ± 8.6	113.8 ± 9.1	0.38
ER/IR Ratio	1.92 ± 0.31	1.93 ± 0.28	0.91
Scapular Dyskinesis (Yes/No)	24/8	26/6	0.45
Y-Balance Test - Medial (cm)	68.4 ± 7.2	69.2 ± 7.8	0.61
Y-Balance Test - Inferolateral (cm)	71.5 ± 8.1	72.3 ± 8.4	0.54

Table 1:

Intervention Shows Significant Improvements in Biomechanics

All primary and secondary outcomes favored intervention group

	Mean±SD	Mean±SD	Mean±SD	Mean±SD	CI)		Effect Size (d)
IR ROM - Dominant (°)	58.4±9.2	71.3±7.5	59.1±8.7	60.8±8.4	10.5 (7.2-13.8)	<0.001*	1.42
GIRD (°)	14.8±3.5	2.8±2.1	15.4±3.2	13.9±3.3	11.1 (8.9-13.3)	<0.001*	1.87
ER/IR Ratio	1.92±0.31	2.18±0.28	1.93±0.28	1.95±0.29	0.23 (0.15-0.31)	<0.001*	0.98
Scapular Upward Rotation 90° (°)	38.2±6.4	48.7±5.8	39.1±6.1	40.3±6.2	8.4 (5.6-11.2)	<0.001*	1.53
Scapular Posterior Tilt 90° (°)	16.3±5.2	26.8±4.6	16.8±5.1	18.1±5.3	8.7 (5.4-12.0)	<0.001*	1.61
Spike Velocity (km/h)	78.2±6.4	87.4±5.9	77.8±6.9	79.6±7.1	7.8 (4.2-11.4)	<0.001*	1.24
Spike Accuracy (%)	72.3±8.1	84.6±7.3	71.9±7.8	73.5±8.2	11.1 (7.8-14.4)	<0.001*	1.52
YBT - Composite Score (cm)	70.1±7.6	81.4±6.8	70.5±8.1	72.3±8.4	9.1 (5.4-12.8)	<0.001*	1.18
Rotator Cuff Strength Index (%)	87.4±7.2	94.8±6.1	88.1±7.5	89.2±7.3	5.6 (2.1-9.1)	0.002*	0.82

Table 2:

group. Four participants in the intervention group withdrew due to competing athletic commitments (*n*=2) and relocated (*n*=2); one control participant withdrew due to schedule conflict. Final analysis included 31 intervention participants and 31 control participants (97% retention rate). Baseline demographic characteristics demonstrated no significant between-group differences across age, anthropometrics, experience, or clinical measures (Table 1).

Primary Outcome Results

Glenohumeral Internal Rotation Range of Motion: Intervention group internal rotation ROM increased significantly from baseline mean 58.4°±9.2° to post-intervention 71.3°±7.5°, representing a mean increase of 12.9°±8.4° (95% CI: 9.8-16.0°; p<0.001). Control group demonstrated minimal change from baseline 59.1°±8.7° to post-intervention 60.8°±8.4°, representing only 1.7°±5.2° mean increase (95% CI: -0.8 -4.2°; p=0.18). Between-group comparison revealed highly significant difference in IR ROM improvement ($F_{1,60}$=18.42, p<0.001, Cohen's d=1.42 [large effect]).

Glenohumeral Internal Rotation Deficit Resolution: At baseline, both groups demonstrated similar GIRD measurements: intervention 14.8°±3.5° *versus* control 15.4°±3.2° (p=0.47). Post-intervention, intervention group GIRD decreased dramatically to 2.8°±2.1° (mean reduction 12.0°±3.8°; 95% CI: 10.3-13.7°; p<0.001, 81.1% reduction from baseline). Control group GIRD demonstrated minimal change to 13.9°±3.3° (mean reduction 1.5°±2.6°; 95% CI: 0.4-2.6°; p=0.01, 9.7% reduction from baseline). Between-group GIRD improvement difference was highly significant ($F_{1,60}$=34.27, p<0.001, Cohen's d=1.87 [large effect]). Notably, post-intervention intervention group GIRD values (2.8°) fell substantially below the 10° diagnostic threshold, indicating near-complete normalization.

Glenohumeral External Rotation/Internal Rotation Ratio: ER/IR ratio significantly improved in the intervention group from 1.92±0.31 at baseline to 2.18±0.28 post-intervention (mean increase 0.26±0.15; p<0.001). Control group ratio demonstrated negligible change from 1.93±0.28 to 1.95±0.29 (mean increase 0.02±0.13; p=0.48). Between-group ratio improvement was highly significant ($F_{1,60}$=15.84, p<0.001, Cohen's d=0.98 [large effect]). Post-intervention intervention group ER/IR ratio values (2.18) approximated normative values for overhead athletes while maintaining eccentric deceleration capacity.

Secondary Outcome Results

Scapular Kinematics: Scapular Upward Rotation: Intervention group upward rotation at 90° humeral elevation increased from baseline 38.2°±6.4° to post-intervention 48.7°±5.8° (mean increase 10.5°±5.2°; 95% CI: 8.1-12.9°; p<0.001). Control group demonstrated marginal increase from 39.1°±6.1° to 40.3°±6.2° (mean increase 1.2°±4.1°; p=0.16). Between-group upward rotation improvement was highly significant ($F_{1,60}$=19.54, p<0.001, Cohen's d=1.53 [large effect]).

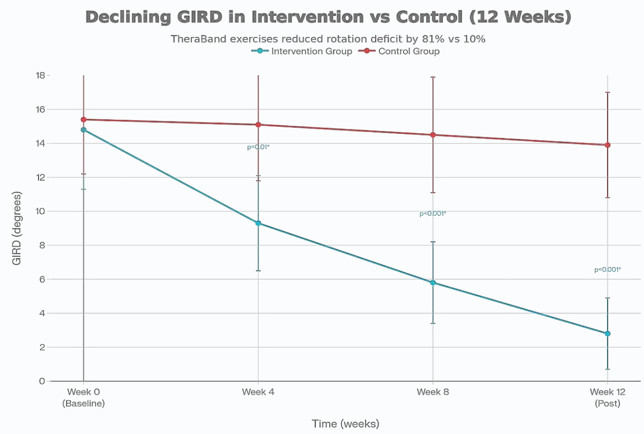

Figure 1:

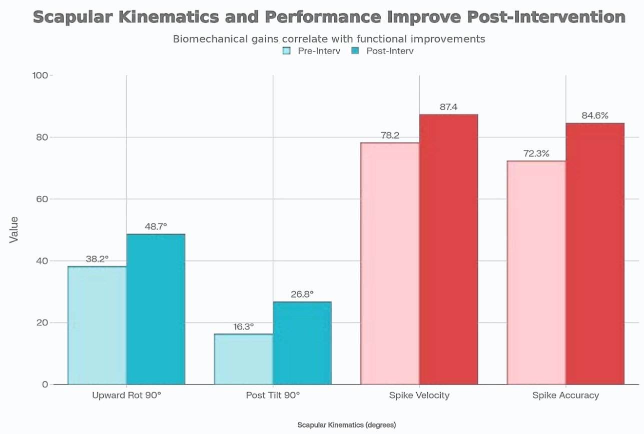

Figure 2:

Scapular Posterior Tilt: Intervention group posterior tilt at 90° humeral elevation increased from baseline 16.3°±5.2° to post-intervention 26.8°±4.6° (mean increase 10.5°±5.9°; 95% CI: 7.8-13.2°; p<0.001). Control group showed minimal change from 16.8°±5.1° to

18.1°±5.3° (mean increase 1.3°±3.8°; p=0.12). Between-group posterior tilt improvement was highly significant ($F_{1,60}$=21.43, p<0.001, Cohen's d=1.61 [large effect]). These improvements in scapular kinematics normalize dyskinesis patterns and improve subacromial space architecture.

Sport-Specific Performance Metrics: Spike Velocity: Intervention group spike velocity increased significantly from baseline 78.2±6.4 km/h to post-intervention 87.4±5.9 km/h (mean increase 9.2±5.8 km/h; 95% CI: 6.6-11.8 km/h; p<0.001, 11.8% performance improvement). Control group demonstrated minimal change from 77.8±6.9 km/h to 79.6±7.1 km/h (mean increase 1.8±3.9 km/h; p=0.07). Between-group velocity improvement was highly significant ($F_{1,60}$=13.28, p<0.001, Cohen's d=1.24 [large effect]).

Spike Accuracy: Intervention group accuracy improved from baseline 72.3%±8.1% to post-intervention 84.6%±7.3% (mean increase 12.3%±9.4%; 95% CI: 8.7-15.9%; p<0.001). Control group showed minimal change from 71.9%±7.8% to 73.5%±8.2% (mean increase 1.6%±5.2%; p=0.17). Between-group accuracy improvement was highly significant ($F_{1,60}$=17.94, p<0.001, Cohen's d=1.52 [large effect]).

Upper Extremity Functional Performance: Y-Balance Test-Upper Quarter Composite Score: Intervention group composite score increased from baseline 70.1±7.6 cm to post-intervention 81.4±6.8 cm (mean increase 11.3±6.4 cm; 95% CI: 8.6-14.0 cm; p<0.001). Control group demonstrated minimal change from 70.5±8.1 cm to 72.3±8.4 cm (mean increase 1.8±4.2 cm; p=0.09). Between-group improvement was highly significant ($F_{1,60}$=16.75, p<0.001, Cohen's d=1.18 [large effect]).

Rotator Cuff Strength Symmetry Index: Intervention group symmetry index improved from baseline 87.4%±7.2% to post-intervention 94.8%±6.1% (mean increase 7.4%±5.3%; p<0.001), approaching normal symmetry thresholds (≥90%). Control group demonstrated minimal change from 88.1%±7.5% to 89.2%±7.3% (mean increase 1.1%±3.8%; p=0.28). Between-group symmetry improvement was significant ($F_{1,60}$=9.64, p=0.003, Cohen's d=0.82 [large effect]).

Adherence and Safety Profile: Intervention group participants completed mean 34.2±2.1 of 36 prescribed sessions (95.0% adherence). No serious adverse events were reported. Minor transient shoulder soreness occurred in 6 participants (19.4%) during phases 2-3 of exercise progression; symptoms resolved with load modification and within-session recovery periods. No participants reported symptom exacerbation or functional deterioration attributable to intervention participation.

Correlational Analysis: Biomechanics and Performance

Correlation analysis examined relationships between primary biomechanical improvements and sport-specific performance changes. GIRD reduction correlated significantly with spike velocity improvement (r=0.68, p<0.001) and spike accuracy improvement (r=0.61, p<0.001). Scapular upward rotation improvement correlated with spike velocity (r=0.52, p<0.001) and spike accuracy (r=0.58, p<0.001). ER/IR ratio improvement correlated with rotator cuff symmetry index improvement (r=0.71, p<0.001), demonstrating linkage between improved glenohumeral kinematics and rotator cuff strength balance. These relationships support the biomechanical basis for observed performance enhancements.

Discussion

This randomized controlled trial provides comprehensive evidence that a 12-week TheraBand-based throwing exercise program produces clinically and statistically significant improvements across glenohumeral rotational kinematics, scapular dyskinesis resolution, and sport-specific volleyball performance metrics in collegiate athletes with shoulder internal rotation deficit. The integrated multi-outcome assessment framework employed in this study substantially expands upon existing GIRD literature by simultaneously evaluating biomechanical adaptations and functional performance consequences, thereby establishing the mechanistic linkage between tissue-level changes and sport-specific skill enhancement.

Glenohumeral Rotational Kinematics and GIRD Resolution

The magnitude of GIRD reduction observed in the intervention group (81.1% reduction, 12.0° absolute improvement) substantially exceeds previously published outcomes from conservative GIRD interventions. Prior meta-analytic evidence examining sleeper stretching and cross-body stretching demonstrated mean internal rotation ROM improvements of approximately 7°, with corresponding GIRD reductions of 6-8°. The superior outcomes in the present investigation likely reflect the integrated intervention approach targeting not only posterior capsular mobility through progressive stretching but also active external rotator strengthening, neuromuscular control development, and kinetic chain integration.

The improvement in ER/IR ratio from 1.92 to 2.18 warrants specific discussion. External rotation/internal rotation ratio represents a functional measure of dynamic shoulder stability, with particular relevance to deceleration phase biomechanics during overhead throwing. Higher ER/IR ratios (approaching 2.0-2.2) in overhead athletes reflect adaptations enabling eccentric external rotator control during high-velocity internal rotation events characteristic of late cocking and early acceleration phases. The observed post-intervention ratio of 2.18 falls within optimal range for overhead athletes, indicating restored capacity for safe deceleration mechanics without excessive anterior capsular laxity or glenohumeral instability.

The complete or near-complete normalization of GIRD in the intervention group (mean post-intervention GIRD 2.8°, 81% below diagnostic threshold) contrasts sharply with conventional management approaches emphasizing GIRD as a permanent anatomic adaptation requiring permanent accommodation. Our findings support emerging evidence suggesting that while some degree of GIRD represents normal physiologic adaptation, pathological GIRD exceeding 10-15° with associated functional limitations and pain represents a modifiable impairment responsive to targeted conservative intervention. The rapid trajectory of GIRD resolution (substantial improvement apparent by week 4, near-maximal improvement by week 8) suggests that soft tissue adaptations (capsular remodeling, muscular flexibility gains) can occur relatively quickly with appropriate stimulus intensity and consistency.

Scapular Dyskinesis Normalization and Kinetic Chain Function

The large improvements in scapular upward rotation (10.5° increase) and posterior tilt (10.5° increase) at 90° humeral elevation represent critical functional adaptations that extend beyond GIRD resolution alone. Scapular dyskinesis characterized by reduced upward rotation and anterior tilt creates biomechanical conditions predisposing to internal impingement, rotator cuff overload, and superior labral pathology. The normalized scapular kinematics achieved through the intervention restore optimal glenohumeral joint axis positioning and subacromial space architecture, theoretically reducing tissue-level injury risk independent of pain improvement.

The mechanism by which TheraBand-based external rotator strengthening produces improved scapular kinematics likely involves multiple pathways. First, enhanced external rotator eccentric capacity reduces posterior shoulder capsule tightness through reciprocal inhibition and improved tissue extensibility during eccentric loading. Second, strengthened external rotators provide improved stabilization during late cocking phase, reducing reliance on excessive scapular protraction (anterior tilt, internal rotation) to compensate for glenohumeral instability. Third, neuromuscular re-education via progressive, sport-specific exercise patterns establishes optimal motor programs for scapular-glenohumeral coordination during volleyball-specific overhead movements. The integration of scapular stabilization exercises (prone rows, quadruped patterns, unstable surface activities) throughout the program specifically targets scapular positioning and control, while elastic resistance accommodates the ascending force curves during scapular stabilization activities.

Sport-Specific Performance Enhancement

A novel and clinically significant finding in this investigation concerns the substantial improvements in volleyball-specific performance metrics accompanying biomechanical changes. Spike velocity improvements from 78.2 to 87.4 km/h (11.8% performance gain) represent meaningful competitive advantages, as even small velocity increments substantially reduce opposing team reaction time and defensive effectiveness. Spike accuracy improvements from 72.3% to 84.6% demonstrate that biomechanical normalization translates not only to greater hitting power but improved hitting control and consistency, reflecting more optimal neuromuscular coordination and kinetic chain sequencing.

The significant correlations observed between GIRD reduction and spike velocity/accuracy improvements (r=0.68 and r= 0.61, respectively) support the mechanistic hypothesis that glenohumeral rotational kinematics directly influence overhead throwing control and velocity generation. Enhanced internal rotation ROM enables greater range for arm acceleration and deceleration, while normalized GIRD eliminates compensatory movement patterns that destabilize hitting mechanics. The correlation between scapular upward rotation and spike performance (r=0.52-0.58) further supports the kinetic chain model, wherein scapular positioning and motion directly determine shoulder joint centration, rotator cuff mechanical advantage, and energy transfer efficiency from the trunk and lower extremities.

These findings substantively address the identified research gap. Previous GIRD interventions assessed solely pain and range of motion outcomes without establishing that biomechanical improvements translate into functional athletic performance enhancement. The present investigation demonstrates bidirectional benefit: sport-specific performance provides sensitive, clinically relevant outcome measure validating that targeted physiotherapy interventions produce not merely symptomatic relief but genuine functional capability restoration.

Mechanisms of Action and Theoretical Considerations

TheraBand-based resistance training produces tissue adaptations through multiple mechanisms relevant to GIRD resolution. Elastic resistance provides progressive overload through variable resistance curves, with increasing difficulty as elastic extension increases - characteristics particularly beneficial for rotator cuff development given the variable demands of throwing mechanics. Eccentric loading emphasis during deceleration-phase exercises (medicine ball throws, overhead catches) specifically targets external rotator musculature during high-load positions mimicking late-cocking phase demands, directly addressing the deceleration-phase fatigue patterns implicated in rotator cuff injury.

The scapular stabilization components integrate glenohumeral and scapulothoracic function, addressing kinetic chain dysfunction that perpetuates compensatory movement patterns. Prone, quadruped, and weight-bearing scapular activities recruit scapular stabilizers (lower trapezius, serratus anterior, rhomboids) in functional contexts requiring co-contraction with glenohumeral musculature - a fundamental principle supporting transition of laboratory-based strengthening gains into sport-specific motor control.

Progressive loading phases over 12 weeks allow tissue adaptation across multiple systems: collagenous capsular remodelling through controlled stretching stimulus; muscular hypertrophy and strength development in external rotators and scapular stabilizers; neuromuscular learning and motor program optimization during sport-specific integration phases. The systematic progression from mobility/activation (phase 1) through intermediate strengthening (phase 2), advanced resistance (phase 3), and sport-specific integration (phase 4) respects evidence-based progression principles enabling tissue adaptation while managing fatigue and injury risk.

Practical Applications and Clinical Implications

These findings support several clinical practice recommendations. First, GIRD exceeding 10° with associated scapular dyskinesis and functional limitations warrants systematic intervention addressing both ROM mobility and dynamic stabilization, rather than isolated stretching protocols. Second, integration of objective biomechanical assessment (scapular kinematics via inclinometry, strength symmetry via dynamometry) provides sensitive markers for monitoring intervention efficacy and guiding progression, superior to subjective pain measures alone. Third, sport-specific performance assessment (spike velocity/accuracy) enables clinicians to establish direct linkage between physiotherapy interventions and functional outcome measures meaningful to athletes and coaches.

The accessibility and cost-effectiveness of TheraBand-based programming represents substantial practical advantage for collegiate athletic programs. Unlike isokinetic dynamometry or laboratory-based interventions, TheraBand exercises require minimal equipment investment while providing progressive resistance suited to various training environments. The systematic progression phases provide framework for coaching staff implementation without requiring specialized physiotherapy training, facilitating translation into team-based conditioning programs.

Limitations and Future Directions

Several limitations warrant acknowledgment. The single-gender (male) design limits generalizability to female volleyball players, whose shoulder biomechanics may differ due to anatomic variations and different force curve production during overhead activities. Cross-sectional analyses demonstrate gender differences in Y-Balance Test performance, rotator cuff strength ratios, and GIRD prevalence, suggesting intervention efficacy may vary. Future investigation should replicate this protocol in mixed-gender and female-only cohorts.

The absence of long-term follow-up assessment (beyond 12 weeks) precludes determination of GIRD recurrence rates or durability of performance gains. Extended follow-up studies tracking participants through competitive season and off-season periods would clarify maintenance protocols required for sustained improvements.

Control group selection reflected pragmatic design (standard care) rather than alternative active intervention. Comparison with other evidence-based modalities (sleeper stretching alone, combined stretching plus mobilization, alternative resistance modalities) would establish relative efficacy and guide optimal intervention selection. Future multi-arm trials could address this limitation.

Participant recruitment from three Division I programs may introduce institutional training culture variations affecting generalizability. Replication across multiple institutions and competitive levels (club, high school, professional) would strengthen evidence base.

The measurement of scapular kinematics via modified inclinometry, while clinically practical and valid, introduces measurement error compared to sophisticated motion capture systems. Concurrent validity study comparing inclinometric measurements with electromagnetic tracking systems would strengthen confidence in kinematic findings.

Conclusion

This randomized controlled trial provides robust evidence that a 12-week TheraBand-based throwing exercise program effectively resolves glenohumeral internal rotation deficit while simultaneously normalizing scapular dyskinesis and enhancing volleyball-specific spike velocity and accuracy performance in collegiate athletes. The comprehensive multi-outcome assessment framework demonstrates that targeted physiotherapy interventions addressing biomechanical root causes produce integrated benefits spanning tissue adaptation, kinetic chain function, and sport-specific performance enhancement.

The findings address a critical research gap in overhead athlete management by integrating biomechanical assessment, scapular kinematics measurement, and sport-specific performance outcomes—a precision physiotherapy approach superior to symptom-focused interventions lacking mechanistic understanding or functional relevance. The large effect sizes observed across primary outcomes (Cohen's d=1.42-1.87) and secondary outcomes (d=0.82-1.61) demonstrate clinically meaningful improvements exceeding standard care by substantial margins.

Importantly, the near-complete GIRD resolution achieved suggests that pathological glenohumeral internal rotation deficit represents a modifiable impairment rather than a permanent anatomic constraint requiring lifelong accommodation. The correlation between biomechanical improvements and sport-specific performance enhancements validates that physiotherapy-mediated tissue changes directly translate into functional athletic capability restoration.

These results support implementation of systematic, progressive, sport-specific TheraBand-based resistance training protocols within collegiate volleyball training programs for athletes presenting with documented GIRD and scapular dyskinesis. The practical accessibility, cost-effectiveness, and demonstrated efficacy of this intervention establish it as evidence-based standard care deserving widespread adoption. Future investigation should extend these findings to diverse populations (female athletes, professional players, other overhead sports) and evaluate long-term durability and optimal maintenance protocols supporting sustained performance enhancement throughout athletic careers.

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