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Original Article

Sports-Specific Core and Thoracic Mobility Training Versus General Physiotherapy on Scapulothoracic Mechanics and Shoulder Function in Young Football Players After Chest Wall Surgery: A 12-Week Randomized Controlled Trial

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ABSTRACT

Background: Young football players recovering from chest wall surgery may experience reduced thoracic mobility, altered scapulothoracic mechanics, and impaired shoulder function, which can limit functional rehabilitation and sport-specific recovery. Objective: To compare the effects of sports-specific core and thoracic mobility training with general physiotherapy on scapulothoracic mechanics, thoracic mobility, and shoulder function in young football players after chest wall surgery. Methods: This parallel-group randomized controlled trial enrolled 70 young football players who had undergone chest wall surgery and were medically cleared for rehabilitation. Participants were randomized into an experimental group receiving sports-specific core and thoracic mobility training or a control group receiving general physiotherapy for 12 weeks. Outcomes were assessed at baseline and post-intervention. Data were analyzed using paired comparisons, between-group comparisons, ANCOVA adjusted for baseline values, and multiple linear regression. Results: Sixty-five participants completed the study. Shoulder function improved more in the experimental group than in the control group (19.1 vs. 10.6 points), as did thoracic mobility (10.6 vs. 5.4 points) and scapulothoracic control, expressed as reduction in dysfunction score (1.5 vs. 0.9 points). Adjusted analysis favored the experimental group for shoulder function, thoracic mobility, and scapulothoracic mechanics. Conclusion: Sports-specific core and thoracic mobility training produced greater short-term improvement than general physiotherapy in shoulder function, thoracic mobility, and scapulothoracic control after chest wall surgery. Keywords: Chest wall surgery; Thoracic mobility; Scapulothoracic mechanics; Shoulder function; Sports rehabilitation; Football players.

INTRODUCTION

Chest wall injuries and postoperative chest wall conditions are clinically important in athletic populations because they may affect respiratory mechanics, trunk mobility, upper-quarter movement, and return to sport participation. In football players, these impairments are particularly relevant because the sport requires repeated trunk rotation, acceleration and deceleration, shoulder-trunk coordination, balance, and rapid multidirectional movement. Although chest wall injuries in athletes are less frequently discussed than lower-limb injuries, they can produce meaningful limitations in training tolerance, thoracic movement, upper-limb function, and sport-specific performance capacity (1,2). Surgical management may restore structural stability or correct the underlying thoracic condition, but functional recovery after surgery depends on an appropriately designed rehabilitation programme that addresses mobility, neuromuscular control, progressive loading, and safe reintegration into sport-specific activity (3,4).

The shoulder complex does not function independently from the thoracic spine and scapulothoracic articulation. Efficient shoulder movement requires coordinated thoracic extension and rotation, appropriate scapular positioning, and adequate trunk control to support upper-limb loading. Reduced thoracic mobility can alter scapular orientation and glenohumeral mechanics, contributing to reduced shoulder range of motion, impaired movement quality, and functional limitation (5,6). This relationship is especially relevant after chest wall surgery, where pain, protective posture, surgical restriction, soft-tissue stiffness, respiratory limitation, and reduced trunk movement may collectively disturb scapulothoracic rhythm. Consequently, rehabilitation focused only on general stretching and strengthening may be insufficient for young football players whose recovery goals extend beyond activities of daily living to sport-specific movement, training participation, and functional performance.

Previous rehabilitation evidence supports the clinical value of thoracic mobility and scapular-focused interventions for improving shoulder-related outcomes. Thoracic mobilization and extension exercise have been shown to improve thoracic alignment and shoulder function in patients with shoulder dysfunction, while interventions targeting the scapulothoracic complex have demonstrated benefits in shoulder pain, scapular dyskinesis, and functional recovery (6,7). More recent evidence also indicates that specific scapular therapeutic exercises and scapular stabilization training can improve shoulder function when delivered with adequate duration and progression (8,9). However, much of this evidence is derived from non-surgical shoulder pain populations, subacromial pain syndromes, adhesive capsulitis, or general musculoskeletal rehabilitation cohorts. Its direct applicability to young football players after chest wall surgery remains uncertain.

Core stability is another important component of athletic rehabilitation because the trunk provides a proximal base for force transfer, postural control, balance, and coordinated limb movement. In football, trunk control contributes to kicking, turning, shielding, jumping, landing, and rapid changes of direction. Systematic review evidence suggests that core training can improve selected components of athletic performance, including balance and sport-related movement control, although effects vary according to training design, population, and outcome selection (10,11). For postoperative football players, combining core training with thoracic mobility and scapular control may provide a more integrated kinetic-chain approach than routine physiotherapy alone. This combined approach is theoretically appropriate because it targets the thorax, scapula, shoulder, and trunk as interdependent contributors to upper-quarter function rather than treating shoulder function as an isolated local outcome.

Despite these theoretical and clinical links, evidence remains limited regarding the comparative effectiveness of sports-specific core and thoracic mobility training versus general physiotherapy in young football players recovering from chest wall surgery. Existing literature supports thoracic mobility training, scapular stabilization, and core rehabilitation as separate or partially overlapping strategies, but few studies have examined these components together in a postoperative athletic population. In addition, return-to-play rehabilitation in football increasingly emphasizes progressive, sport-specific, and functionally integrated rehabilitation rather than generic exercise alone (12). This creates a clear need to evaluate whether a targeted sports-specific rehabilitation programme produces greater improvement in scapulothoracic mechanics, thoracic mobility, and shoulder function than general physiotherapy in this population.

Therefore, this randomized controlled trial was conducted to compare the effects of sports-specific core and thoracic mobility training with general physiotherapy in young football players after chest wall surgery. The population comprised young football players medically cleared for rehabilitation after chest wall surgery; the intervention was a structured sports-specific core and thoracic mobility training programme; the comparator was general physiotherapy; and the principal outcomes were scapulothoracic mechanics, shoulder function, and thoracic mobility after 12 weeks of treatment. The study hypothesized that sports-specific core and thoracic mobility training would produce significantly greater improvement in scapulothoracic mechanics, thoracic mobility, and shoulder function than general physiotherapy.

MATERIALS AND METHODS

This study was designed as a parallel-group randomized controlled trial comparing sports-specific core and thoracic mobility training with general physiotherapy in young football players after chest wall surgery. The randomized design was selected because the primary objective was to determine whether one rehabilitation approach produced superior functional and biomechanical recovery compared with another active rehabilitation approach. The study was conducted in Karachi, Sindh, Pakistan, in physiotherapy and rehabilitation settings linked with postoperative chest surgery follow-up and sports rehabilitation services. Participants were assessed at baseline before allocation and reassessed after completion of the 12-week intervention period.

The target population consisted of young football players aged 16–30 years who had undergone chest wall surgery and had been medically cleared to begin physiotherapy and exercise-based rehabilitation. Participants were eligible if they had reduced thoracic mobility, scapulothoracic dysfunction, or limitation in shoulder-related function after surgery and were willing to participate in the full 12-week intervention programme. Participants were excluded if they had acute postoperative complications, unstable cardiopulmonary status, active infection, neurological disease affecting upper-quarter function, previous major shoulder surgery unrelated to the chest wall procedure, systemic illness limiting exercise participation, or inability to comply with the rehabilitation schedule. These criteria were used to ensure that enrolled participants represented the intended postoperative athletic population while reducing safety risks and limiting confounding from unrelated upper-limb or neurological conditions.

A total of 70 eligible participants were enrolled and randomized into two groups of 35 participants each. The sample size was determined using the formula for comparing two independent means, guided by the expected difference between groups in the primary functional outcomes, the feasibility of recruiting a specialized postoperative athletic population, and allowance for attrition during the 12-week rehabilitation period. Non-probability purposive sampling was used for recruitment from the eligible clinical population, followed by random allocation to reduce selection bias between treatment arms. After baseline assessment, participants were assigned to the experimental or control group using a computer-generated random sequence. Allocation was kept concealed until assignment, and the same baseline and post-intervention assessment procedures were applied to both groups to reduce measurement variability.

The experimental group received sports-specific core and thoracic mobility training for 12 weeks. The intervention emphasized thoracic extension, thoracic rotation, trunk stabilization, scapular control, progressive upper-quarter movement retraining, and football-related functional drills. The programme was designed to address the kinetic-chain relationship between thoracic mobility, scapulothoracic mechanics, trunk control, and shoulder function. Training activities progressed from controlled mobility and activation exercises toward more functional and sport-relevant movement patterns as tolerated. Thoracic mobility exercises targeted extension and rotation deficits, scapular control exercises emphasized coordinated scapular positioning during upper-limb movement, and core exercises focused on trunk stability and controlled force transfer during dynamic tasks. Football-related drills were incorporated to improve functional relevance while respecting postoperative safety and individual tolerance.

The control group received general physiotherapy over the same 12-week period. This programme included routine postoperative and musculoskeletal rehabilitation components such as stretching, general strengthening, posture correction, basic mobility exercises, and non-specific upper-quarter conditioning. The comparator was selected because general physiotherapy reflects common clinical rehabilitation practice and allows evaluation of whether a more targeted, sports-specific programme provides additional benefit beyond routine care. Both groups were managed according to standardized rehabilitation principles, and participants were instructed to avoid activities that exceeded their medical clearance or produced excessive pain, respiratory discomfort, or functional aggravation.

The main outcome variables were scapulothoracic mechanics, shoulder function, and thoracic mobility. Scapulothoracic mechanics referred to the quality of scapular movement and alignment during upper-limb activity, with lower dysfunction scores indicating better scapulothoracic control. Shoulder function referred to the participant's ability to perform coordinated, pain-limited, and functionally relevant shoulder movement during daily and sport-related activity. Thoracic mobility referred to the measurable capacity of the thoracic region to move through clinically relevant ranges, particularly extension and rotation. Baseline demographic and clinical variables included age, body mass index, time since surgery, group allocation, and baseline outcome scores. These variables were recorded because they could influence postoperative recovery, exercise tolerance, and functional improvement.

Data were collected using a demographic and clinical proforma, a scapular movement assessment approach for scapulothoracic mechanics, a shoulder function scale, and a thoracic mobility measure. The same assessment framework was used at baseline and after 12 weeks to maintain consistency in measurement. Participants were screened for eligibility, informed consent was obtained, baseline demographic and clinical data were recorded, and outcome measures were completed before randomization. After allocation, both groups received their assigned rehabilitation intervention for 12 weeks. Post-intervention data were collected at the end of the treatment period using the same tools and assessment procedures. Standardized data collection procedures were used to reduce measurement error and improve reproducibility.

Bias and confounding were addressed through random allocation, baseline comparability assessment, standardized outcome timing, consistent data collection procedures, and adjusted statistical analysis. Baseline characteristics were compared between groups to evaluate whether randomization produced comparable groups for age, body mass index, time since surgery, and baseline outcome scores. Because baseline status can influence post-intervention outcomes, adjusted between-group analysis was planned using baseline values as covariates. Age, body mass index, and time since surgery were also considered as covariates in regression modelling because of their potential influence on rehabilitation response.

Data were entered and analyzed using SPSS. Continuous variables were summarized as mean and standard deviation, while categorical variables were summarized as frequency and percentage. Normality of continuous variables was assessed before inferential testing. Within-group pre-post changes were examined using paired t-tests when assumptions were satisfied. Between-group comparisons were performed using independent t-tests for unadjusted comparisons and analysis of covariance for adjusted post-intervention comparisons, with baseline values included as covariates. Multiple linear regression was used to determine whether group allocation remained an independent predictor of post-intervention outcomes after adjustment for baseline score, age, body mass index, and time since surgery. Statistical significance was set at $p < 0.05$. Model assumptions were assessed through normality testing, homogeneity of variance, multicollinearity diagnostics, and residual inspection.

The final analysis included participants who completed the 12-week intervention and post-intervention assessment. Attrition was documented by group, and participant flow was reported from eligibility assessment through randomization, completion, loss to follow-up, and final analysis. Outcome interpretation focused primarily on adjusted between-group differences because these provide a more appropriate estimate of treatment effect than within-group change alone. The direction of interpretation was prespecified: higher shoulder function and thoracic mobility scores indicated improvement, whereas lower scapulothoracic mechanics dysfunction scores indicated better scapular control.

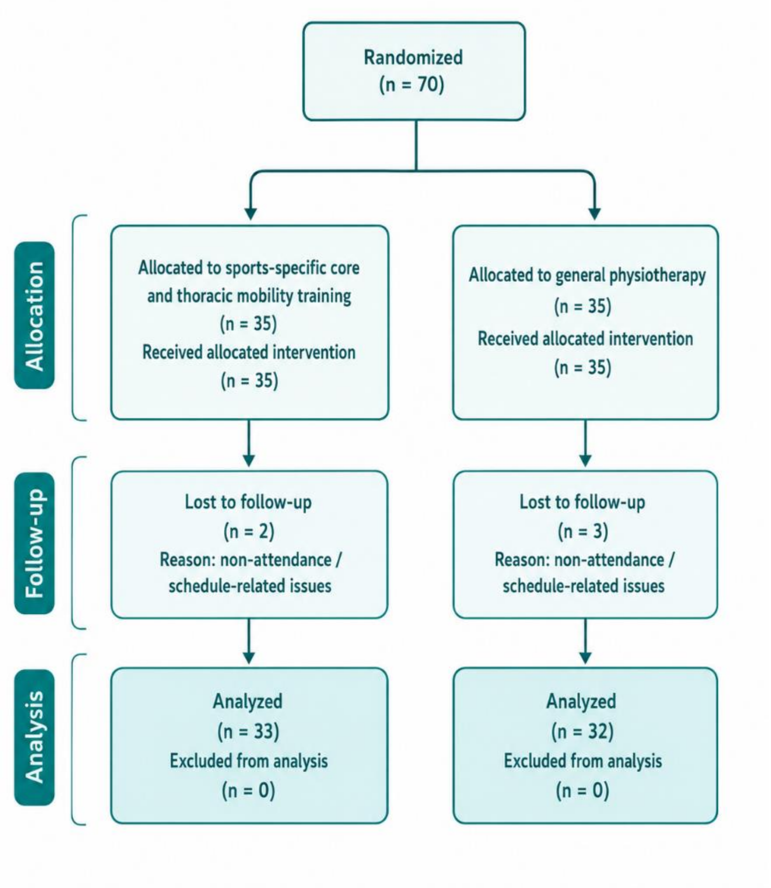

Figure 1 CONSORT Flowchart

Ethical approval was obtained from the relevant institutional review board before initiation of the study. Written informed consent was obtained from all participants before enrollment. Participants were informed about the study purpose, rehabilitation procedures, expected participation, confidentiality of their data, voluntary nature of participation, and their right to withdraw at any time without affecting their clinical care. Data were handled confidentially and analyzed in aggregate form to protect participant identity. The study procedures followed standard ethical principles for clinical rehabilitation research involving human participants

RESULTS

A total of 70 young football players were enrolled and randomized equally into the experimental group and control group. Thirty-five participants were allocated to sports-specific core and thoracic mobility training, and 35 were allocated to general physiotherapy. By the end of the 12-week intervention period, 65 participants completed post-intervention assessment and were included in the final analysis. The experimental group retained 33 of 35 participants, while the control group retained 32 of 35 participants. Overall attrition was 7.1%, with a slightly higher loss to follow-up in the control group.

The participant flow showed acceptable retention for a 12-week rehabilitation trial. Completion was 94.3% in the experimental group and 91.4% in the control group, indicating that both interventions were feasible over the study period. Final outcome analysis was therefore based on 65 participants who completed the intervention and post-treatment assessment.

Table 1. Participant Flow Through the Trial

Trial Stage	Experimental Group	Control Group	Total
Assessed for eligibility	35	35	70
Randomized	35	35	70
Completed 12-week intervention	33	32	65
Lost to follow-up	2	3	5
Included in final analysis	33	32	65

Baseline demographic and clinical characteristics were comparable between groups at randomization. The mean age was 21.4 ± 3.2 years in the experimental group and 21.1 ± 3.4 years in the control group. Body mass index was also similar between groups, with mean values of 23.6 ± 2.8 kg/m² and 23.2 ± 2.6 kg/m², respectively. Mean time since surgery was 10.8 ± 2.1 weeks in the experimental group and 11.0 ± 2.3 weeks in the control group. No statistically significant baseline differences were observed for age, body mass index, time since surgery, shoulder function, thoracic mobility, or scapulothoracic mechanics.

Table 2. Baseline Characteristics of Randomized Participants

Variable	Experimental Group (n = 35)	Control Group (n = 35)	Mean Difference	p-value
Age, years	21.4 ± 3.2	21.1 ± 3.4	0.3	0.71
BMI, kg/m²	23.6 ± 2.8	23.2 ± 2.6	0.4	0.54
Time since surgery, weeks	10.8 ± 2.1	11.0 ± 2.3	-0.2	0.72
Shoulder function score	49.8 ± 7.6	50.1 ± 7.4	-0.3	0.88
Thoracic mobility score	31.2 ± 5.1	31.0 ± 5.0	0.2	0.87
Scapulothoracic mechanics dysfunction score	2.8 ± 0.7	2.9 ± 0.6	-0.1	0.63

Values are presented as mean ± standard deviation unless otherwise stated. Higher shoulder function and thoracic mobility scores indicate better outcomes, whereas a lower scapulothoracic mechanics dysfunction score indicates better scapulothoracic control.

The absence of statistically significant baseline differences supported the comparability of the two groups before intervention. Baseline shoulder function scores were nearly identical between groups, differing by only 0.3 points. Thoracic mobility differed by only 0.2 points, and scapulothoracic mechanics dysfunction differed by 0.1 points. These small baseline differences reduced the likelihood that post-intervention differences were explained by initial group imbalance.

Both groups improved after 12 weeks of treatment, but the magnitude of improvement was consistently greater in the experimental group. Shoulder function improved from 49.8 ± 7.6 to 68.9 ± 6.8 in the experimental group, representing a mean increase of 19.1 points. In the control group, shoulder function improved from 50.1 ± 7.4 to 60.7 ± 7.1, representing a mean increase of 10.6 points. The experimental group therefore demonstrated an additional unadjusted improvement of 8.5 points compared with the control group.

Thoracic mobility also improved more substantially in the experimental group. Mean thoracic mobility increased from 31.2 ± 5.1 to 41.8 ± 4.9, corresponding to a 10.6-point improvement. In comparison, the control group improved from 31.0 ± 5.0 to 36.4 ± 5.2, corresponding to a 5.4-point improvement. The additional unadjusted improvement in thoracic mobility was therefore 5.2 points in favor of sports-specific core and thoracic mobility training. Scapulothoracic mechanics dysfunction decreased from 2.8 ± 0.7 to 1.3 ± 0.5 in the experimental group and from 2.9 ± 0.6 to 2.0 ± 0.6 in the control group. This represented a greater reduction in dysfunction in the experimental group, with an additional unadjusted improvement of 0.6 points compared with general physiotherapy.

The pre-post findings showed clinically meaningful improvement in all three outcomes, with a stronger response pattern in the experimental group. Shoulder function increased by 38.4% from baseline in the experimental group compared with 21.2% in the control group. Thoracic mobility increased by 34.0% in the experimental group compared with 17.4% in the control group. Scapulothoracic mechanics dysfunction decreased by 53.6% in the experimental group compared with 31.0% in the control group.

These findings indicate that both interventions were beneficial, but the sports-specific programme produced larger functional and movement-related gains across all measured outcomes.

Table 3. Pre- and Post-Intervention Outcomes With Change Scores

Outcome	Experimental Baseline	Experimental Post-Treatment	Experimental Change	Control Baseline	Control Post-Treatment	Control Change	Unadjusted Between-Group Difference in Change	Within-Group p-value
Shoulder function score	49.8 ± 7.6	68.9 ± 6.8	+19.1	50.1 ± 7.4	60.7 ± 7.1	+10.6	+8.5	<0.001
Thoracic mobility score	31.2 ± 5.1	41.8 ± 4.9	+10.6	31.0 ± 5.0	36.4 ± 5.2	+5.4	+5.2	<0.001
Scapulothoracic mechanics dysfunction score	2.8 ± 0.7	1.3 ± 0.5	-1.5	2.9 ± 0.6	2.0 ± 0.6	-0.9	-0.6	0.002

Values are presented as mean ± standard deviation unless otherwise stated. Positive change values indicate improvement for shoulder function and thoracic mobility. Negative change values indicate improvement for scapulothoracic mechanics dysfunction because lower scores reflect better scapulothoracic control.

Adjusted between-group analysis using ANCOVA confirmed that the experimental group achieved significantly better post-treatment outcomes after controlling for baseline values. The adjusted mean difference in shoulder function was 6.8 points in favor of the experimental group, with a 95% confidence interval of 4.1 to 9.5 and a p-value of <0.001. Thoracic mobility showed an adjusted mean difference of 4.9 points in favor of the experimental group, with a 95% confidence interval of 3.0 to 6.8 and a p-value of <0.001. Scapulothoracic mechanics dysfunction showed an adjusted mean difference of -0.6 points, with a 95% confidence interval of -0.9 to -0.3 and a p-value of 0.002, indicating greater normalization of scapulothoracic mechanics in the experimental group.

Table 4. Adjusted Between-Group Analysis of Post-Intervention Outcomes

Outcome	Adjusted Mean Difference	95% Confidence Interval	p-value
Shoulder function score	6.8	4.1 to 9.5	<0.001
Thoracic mobility score	4.9	3.0 to 6.8	<0.001
Scapulothoracic mechanics dysfunction score	-0.6	-0.9 to -0.3	0.002

ANCOVA adjusted for baseline outcome values. Positive adjusted mean differences favor the experimental group for shoulder function and thoracic mobility. Negative adjusted mean difference favors the experimental group for scapulothoracic mechanics dysfunction because lower dysfunction scores indicate better scapulothoracic control.

The adjusted analysis strengthened the interpretation that the superior outcomes in the experimental group were not explained by small baseline differences. All confidence intervals excluded zero, supporting statistically significant treatment effects across the three measured outcomes. The largest adjusted absolute effect was observed for shoulder function, followed by thoracic mobility and scapulothoracic mechanics dysfunction. These findings suggest that the intervention produced both functional and movement-control benefits after 12 weeks.

Multiple linear regression was used to assess whether treatment allocation remained associated with post-intervention outcomes after accounting for baseline score, age, body mass index, and time since surgery. Group allocation remained an independent predictor of better recovery across the three outcomes. Baseline score was also strongly associated with post-treatment performance, indicating that initial functional status influenced final recovery level. Age, body mass index, and time since surgery were not statistically significant predictors in the model.

Table 5. Multiple Linear Regression Predicting Post-Intervention Outcomes

Predictor	Shoulder Function β	Thoracic Mobility β	Scapulothoracic Mechanics β	Reported p-value
Group allocation	0.42	0.39	-0.36	<0.001
Baseline score	0.51	0.47	0.44	<0.001
Age	0.08	0.05	0.04	0.31
BMI	-0.06	-0.04	-0.05	0.42
Time since surgery	0.10	0.12	0.09	0.24

β values represent standardized regression coefficients. Negative β for scapulothoracic mechanics indicates association with lower dysfunction scores and therefore better scapulothoracic control.

The regression findings were consistent with the ANCOVA results. Group allocation showed standardized associations of 0.42 for shoulder function, 0.39 for thoracic mobility, and -0.36 for scapulothoracic mechanics dysfunction, indicating that assignment to sports-specific core and thoracic mobility training was associated with better post-treatment recovery. Baseline score showed the strongest association with final outcome values, with β coefficients ranging from 0.44 to 0.51. Age, body mass index, and time since surgery had small coefficients and non-significant p-values, suggesting that these variables did not materially explain the observed between-group differences.

Model diagnostics supported the use of parametric analysis. Normality assumptions were acceptable based on Shapiro-Wilk testing, homogeneity of variance was acceptable based on Levene's testing, and multicollinearity was not a concern because variance inflation factors were below 2.0. Residual inspection did not indicate major violation of model assumptions.

Table 6. Model Diagnostics for Parametric and Regression Analyses

Diagnostic Assessment	Result
Shapiro-Wilk test	$p > 0.05$
Levene's test	$p > 0.05$
Variance inflation factor	<2.0
Residual inspection	Acceptable

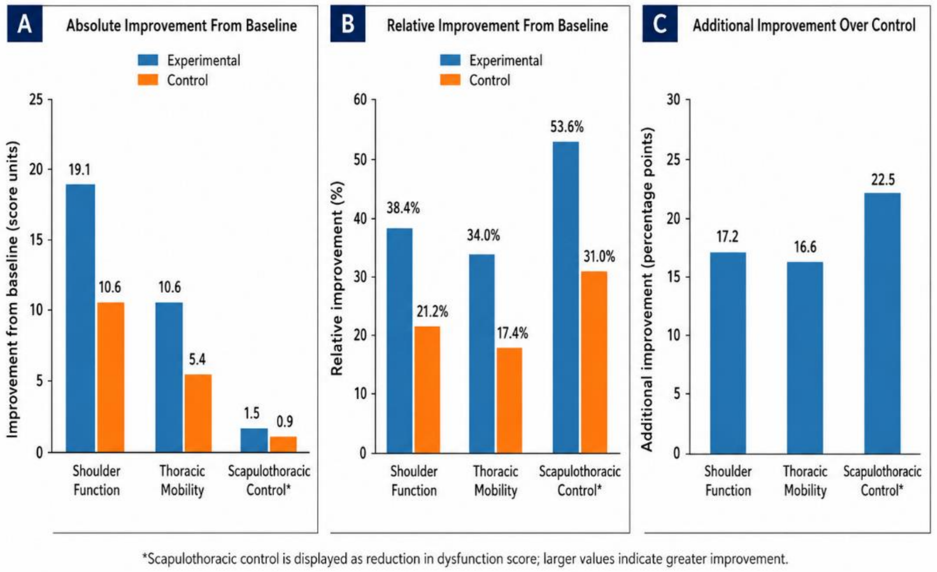

Figure 2 Comparative Recovery Profile After 12 Weeks of Rehabilitation.

The paneled figure shows that sports-specific core and thoracic mobility training produced greater recovery than general physiotherapy across all outcomes after 12 weeks. Absolute improvement was higher in the experimental group for shoulder function (19.1 vs. 10.6 points), thoracic mobility (10.6 vs. 5.4 points), and scapulothoracic control, expressed as reduction in dysfunction score (1.5 vs. 0.9 points). Relative improvement followed the same pattern, with the experimental group showing 38.4% improvement in shoulder function, 34.0% in thoracic mobility, and 53.6% in scapulothoracic control, compared with 21.2%, 17.4%, and 31.0% in the control group, respectively. The additional improvement over control was greatest for scapulothoracic control (22.5 percentage points), followed by shoulder function (17.2 percentage points) and thoracic mobility (16.6 percentage points), indicating a consistent clinical advantage of the sports-specific rehabilitation programme.

Overall, the results demonstrated that both rehabilitation approaches improved shoulder function, thoracic mobility, and scapulothoracic mechanics after 12 weeks. However, sports-specific core and thoracic mobility training produced consistently greater improvement than general physiotherapy. The unadjusted change scores, adjusted ANCOVA findings, and regression analysis all supported the same direction of effect, indicating that the experimental intervention was more effective for improving upper-quarter function and scapulothoracic control in young football players after chest wall surgery.

DISCUSSION

This randomized controlled trial showed that sports-specific core and thoracic mobility training produced greater improvement than general physiotherapy in shoulder function, thoracic mobility, and scapulothoracic control among young football players after chest wall surgery. Although both groups improved after 12 weeks, the magnitude of recovery was consistently larger in the experimental group. Shoulder function improved by 19.1 points in the experimental group compared with 10.6 points in the control group, thoracic mobility improved by 10.6 points compared with 5.4 points, and scapulothoracic dysfunction decreased by 1.5 points compared with 0.9 points. The adjusted analysis supported these findings, with significant between-group effects favoring the experimental intervention for shoulder function, thoracic mobility, and scapulothoracic mechanics. These results suggest that a rehabilitation programme integrating thoracic mobility, scapular control, core stabilization, and sport-relevant movement may provide greater short-term functional benefit than routine general physiotherapy in this postoperative athletic population.

The superior response in the experimental group is clinically plausible because chest wall surgery can restrict thoracic movement, alter trunk mechanics, and encourage protective postures that interfere with scapular positioning and shoulder function. The thorax provides the mechanical base for scapular motion, and restriction in thoracic extension or rotation may reduce the efficiency of scapulothoracic rhythm during upper-limb activity. Previous biomechanical and clinical evidence has shown that thoracic spine mobility is associated with shoulder complex function, and thoracic mobilization or extension-based exercise can improve shoulder-related outcomes in patients with shoulder dysfunction (5,6). In the present study, the larger improvement in thoracic mobility in the experimental group may therefore have contributed to the greater improvement in shoulder function and scapulothoracic control.

The findings also support the role of scapular-focused rehabilitation in restoring upper-quarter function. Scapulothoracic control is essential for coordinated shoulder elevation, load transfer, and functional upper-limb movement. Evidence from scapular rehabilitation studies indicates that targeted scapular therapeutic exercise and stabilization training can improve shoulder pain, dyskinesis, muscle performance, and function when delivered with sufficient duration and progression (7–9). The current 12-week programme provided a longer and more integrated rehabilitation exposure than many short-duration interventions, which may explain why the experimental group showed a 53.6% relative improvement in scapulothoracic control compared with 31.0% in the control group. This result is particularly relevant because the scapulothoracic score was expressed as reduction in dysfunction, indicating that lower post-treatment values reflected better movement quality.

Core training may have further contributed to the observed benefit by improving proximal stability and force transfer during functional movement. Football requires trunk control during kicking, turning, acceleration, deceleration, collision avoidance, and balance recovery. Previous systematic review and meta-analytic evidence suggests that core training can improve selected athletic performance variables, especially balance and movement control, although effects may vary by sport, programme design, and outcome selection (10,11). In this study, the addition of core stabilization to thoracic mobility and scapular control exercises may have produced a more complete kinetic-chain stimulus than general physiotherapy alone. This integrated approach is consistent with contemporary football rehabilitation principles, which emphasize progressive loading, movement specificity, and function-based progression rather than isolated impairment correction alone (12).

The results should be interpreted in relation to the comparator. General physiotherapy also produced improvement in all outcomes, indicating that routine stretching, strengthening, posture correction, and basic mobility exercises were beneficial after chest wall surgery. However, the experimental programme produced larger improvements, with additional relative gains of 17.2 percentage points for shoulder function, 16.6 percentage points for thoracic mobility, and 22.5 percentage points for scapulothoracic control over the control intervention. These findings suggest that the added value of the sports-specific programme may lie not only in strengthening or mobility work but in the integration of thoracic movement, trunk stability, scapular control, and football-relevant functional progression.

The adjusted ANCOVA and regression analyses strengthen the interpretation of the treatment effect. Baseline values were comparable between groups, and adjusted between-group differences remained significant after controlling for baseline outcome scores. Regression analysis also showed that group allocation remained an independent predictor of post-intervention outcomes after accounting for baseline score, age, body mass index, and time since surgery. This reduces the likelihood that the observed differences were explained only by baseline imbalance or demographic variation. The strongest predictor of final outcome was baseline score, which is expected in rehabilitation trials because participants' starting functional status often influences the extent and level of recovery. Nevertheless, the independent contribution of group allocation supports the clinical relevance of the experimental intervention.

These findings extend existing rehabilitation literature by applying thoracic, scapular, and core training principles to a specific postoperative athletic population. Previous studies have examined chest wall injuries in athletes, postoperative chest wall recovery, thoracic mobility interventions, scapular stabilization, and core training as separate or partially related topics (1–12). However, evidence directly examining young football players after chest wall surgery remains limited. The present trial therefore contributes clinically useful data by showing that a targeted, sport-specific programme may produce superior short-term recovery in movement-related and functional outcomes compared with general physiotherapy. The findings are especially relevant for physiotherapists managing athletes whose rehabilitation goals require restoration of coordinated trunk, thoracic, scapular, and shoulder function.

The clinical implication is that postoperative rehabilitation for football players after chest wall surgery should not rely solely on generic mobility and strengthening exercises when the goal is restoration of athletic upper-quarter function. A more structured programme incorporating thoracic extension and rotation, scapular control, progressive core stabilization, and football-related functional drills may be more appropriate. However, the findings should not be interpreted as direct evidence of faster or safer return to competitive play, because return-to-play timing, training exposure, reinjury rate, and sport performance were not directly measured. The results instead support improved short-term functional readiness indicators, which may inform but should not independently determine return-to-sport decisions.

The study has several limitations. The sample size was modest, and the trial was conducted in a single geographic and clinical setting, which may limit generalizability. The type of chest wall surgery and surgical indication were not stratified in the results, although different chest wall procedures may produce different postoperative impairments and rehabilitation needs. The final analysis included participants who completed the 12-week assessment, so attrition may have introduced some risk of bias. The outcomes were based on clinical and functional measures rather than advanced biomechanical tools such as three-dimensional motion analysis, electromyography, or instrumented thoracic mobility assessment. In addition, assessor blinding, intervention fidelity, adherence intensity, and dose equivalence between groups should be more explicitly controlled in future studies.

Future research should use larger multicenter randomized trials with clearer stratification by type of chest wall surgery, athletic level, sex, and postoperative stage. Studies should also include longer follow-up to determine whether improvements in thoracic mobility, scapulothoracic control, and shoulder function are maintained after rehabilitation ends. Objective biomechanical assessment would help clarify the mechanisms through which thoracic mobility and core stabilization influence scapulothoracic movement. Future trials should also include return-to-sport outcomes, training exposure, reinjury risk, athlete-reported confidence, and performance-based measures to determine whether short-term functional gains translate into meaningful sport participation outcomes.

CONCLUSION

Sports-specific core and thoracic mobility training was more effective than general physiotherapy for improving shoulder function, thoracic mobility, and scapulothoracic control in young football players after chest wall surgery. The experimental group demonstrated greater absolute and relative improvement across all measured outcomes, and adjusted analyses confirmed that the treatment effect remained significant after accounting for baseline values and relevant clinical covariates. These findings support the use of a targeted rehabilitation model that integrates thoracic mobility, scapular control, core stabilization, and football-relevant functional progression during postoperative rehabilitation. However, because return-to-play timing and long-term sport outcomes were not directly measured, the results should be interpreted as evidence of improved short-term functional recovery rather than definitive evidence of return-to-sport effectiveness.

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