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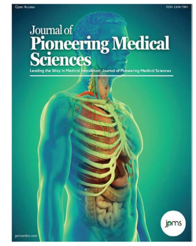

Effectiveness of Total Resistance Exercise on Flexibility and Core Strength in College-Level Cricket Players with Lower Crossed Syndrome: A Randomized Controlled Trial

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Abstract **Background:** Lower Crossed Syndrome (LCS) is a widespread postural impairment among athletes, marked by tightness of the hip flexors and lumbar extensors alongside weakness of the gluteal and abdominal muscles. Total Resistance Exercise (TRX), a suspension-based training method, had not previously been compared directly with Conventional Exercise (CE) in cricketers affected by LCS. This trial set out to determine which approach more effectively improves flexibility and core strength among college-level cricket players with LCS. **Methods:** Thirty-six male cricket players aged 18-25 years with a clinical diagnosis of LCS were randomized into two equal groups of 18: A TRX group (Group 1) and a conventional exercise group (Group 2), using a computer-generated randomization sequence with allocation concealed in sequentially numbered, opaque, sealed envelopes. Sample size was calculated a priori with G*Power 3.1 (large effect size, $\alpha = 0.05$, power = 80%), indicating a minimum of 18 participants per group. Both groups trained three times weekly for six weeks, roughly 50 minutes per session. Flexibility and core strength were evaluated with the Sit and Reach Test (SRT), Double Leg Lowering Test (DLLT) and Single Leg Glute Bridge Test (SLGBT) at baseline, Week 3 and Week 6. **Results:** Both groups improved significantly at every time point ($p<0.001$). The TRX group achieved significantly greater improvement than the CE group on all three outcomes at Week 6: SRT flexibility (mean difference 4.32 cm, 95% CI 3.24-5.39, Cohen's d = 2.72, $p<0.001$), DLLT lumbopelvic stability (-6.96°, 95% CI -8.23 to -5.69, d = -3.71, $p<0.001$) and SLGBT gluteal endurance (14.60 s, 95% CI 12.63-16.55, d = 5.01, $p<0.001$), showing a consistent TRX advantage across all outcomes rather than the split pattern originally hypothesized. As only male college-level cricketers were enrolled, these findings should be interpreted with this population restriction in mind when considering external validity. **Conclusions:** TRX produced significantly greater improvement than conventional exercise across all three outcomes-flexibility, lumbopelvic stability and gluteal endurance-in cricket players with LCS. While CE also produced meaningful within-group gains, TRX was the superior intervention on every outcome measured, indicating that TRX should be considered the preferred rehabilitation approach for this population, with CE potentially serving as an adjunct pending further study of combined protocols.

Key Words Resistance Training, Lower Crossed Syndrome, Core Stability, Athletic Performance, Rehabilitation Exercise

INTRODUCTION

Lower Crossed Syndrome (LCS) is a recognizable postural and musculoskeletal pattern in which tightness of the lumbar extensors and hip flexors coexists with weakness of the abdominal and gluteal muscles, disrupting the reciprocal balance between global and local trunk stabilizers that keeps the lumbar spine mechanically sound [1]. This imbalance alters lumbopelvic alignment, increases anterior pelvic tilt and lumbar lordosis and compromises spinal stability, often contributing to persistent low back pain and functional restriction [2].

Core stability is widely regarded as a foundational element of athletic function, providing the proximal control on which efficient limb movement and power generation depend [3]. The clinical relevance of LCS is not confined to sport, however: female office workers with LCS display measurable changes in head tilt, craniovertebral angle, sagittal shoulder angle and trunk flexion while seated, illustrating how lumbopelvic muscle imbalance can compromise upper-body posture even during sedentary occupational tasks [4].

Effective management of LCS depends on targeted rehabilitation rather than passive care. Meta-analytic evidence supports Global Postural Re-Education as an effective strategy for reducing pain and improving function in LCS-related chronic non-specific low back pain, reinforcing that structured corrective exercise is central to recovery [5].

LCS also occurs frequently across occupational and clinical groups. A cross-sectional study of housemaids reported a high prevalence of hip flexor tightness, gluteal weakness and reduced abdominal strength, indicating that repetitive, flexion-dominant postures are a common precipitating factor for the syndrome well beyond athletic populations [6].

Trunk musculature plays a particularly protective role in cricket. Magnetic resonance imaging has shown that a smaller cross-sectional area of the lumbar multifidus is a specific predictor of low back injury among elite fast bowlers, implicating the kind of deep trunk stabilizer weakness seen in LCS as a mechanism of cricket-related spinal injury [7]. Structured, season-long conditioning has also been shown to meaningfully influence power, speed, agility and endurance in elite cricketers, indicating that trunk- and lower-limb-focused training can be monitored and adapted across a competitive cycle [8]. Although dedicated epidemiological data on the prevalence of LCS specifically within cricketing populations remain scarce, the repetitive, flexion-dominant loading of bowling, batting and fielding plausibly predisposes cricketers to the hip-flexor tightness and gluteal weakness that define the syndrome, underscoring the need for cricket-specific rehabilitation evidence such as that generated by this trial.

Cricket involves repetitive, asymmetrical actions such as bowling, batting and fielding, movements that LCS can compromise while raising injury risk. Despite this, suspension-based training methods such as Total Resistance Exercise (TRX) have rarely been evaluated head-to-head against conventional exercise in cricketers presenting with LCS. Prior TRX-based rehabilitation research in athletic populations, including improved core strength and stability in young athletes [9], enhanced paraspinal and abdominal activation relative to stable-surface exercise [10] and gains in postural stability, lumbopelvic control and proprioception relative to isometric-isotonic floor-based training [20], provides a strong rationale for extending TRX evaluation to cricketers with LCS, a population in which this approach has not previously been tested. This trial therefore compared TRX with conventional exercise for improving flexibility and core strength in college-level cricket players with LCS.

Objectives

The primary objective of this trial was to compare the effectiveness of TRX suspension training versus conventional exercise on flexibility (Sit and Reach Test) in college-level cricket players with Lower Crossed Syndrome. Secondary objectives were to compare the two interventions with respect to core strength/lumbopelvic stability (Double Leg Lowering Test) and gluteal endurance (Single Leg Glute Bridge Test). It was hypothesized that TRX would produce greater improvements than conventional exercise across these outcomes, given its greater proprioceptive and neuromuscular demand.

METHODS

Study Design

This was a randomized controlled trial (RCT) designed and reported in accordance with the CONSORT (Consolidated Standards of Reporting Trials) guidelines. A completed CONSORT 2010 checklist and the trial registration number will be submitted alongside the manuscript, in full compliance with CONSORT reporting requirements for randomized controlled trials.

Study Setting

The trial was conducted at the Saveetha Physical Education Department in collaboration with Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai.

Participants

Thirty-six male college-level cricket players aged 18-25 years were recruited from the Saveetha Physical Education Department. Sixty candidates were initially assessed for eligibility; 24 were excluded (18 did not meet the inclusion criteria, four declined to participate and two were excluded for other reasons), leaving 36 players who were enrolled and randomized. LCS was confirmed through postural assessment, the Thomas test and the prone hip extension test, together with below-normative scores on both the SRT and DLLT. Recruitment from a single institution and inclusion of only male athletes were accepted trade-offs for feasibility and homogeneity of the sample. However, these choices should be considered when generalizing the findings to female athletes, other competitive levels or multi-center populations.

Sample Size Calculation

The required sample size was calculated a priori using G*Power version 3.1 (Heinrich-Heine-Universität Düsseldorf, Germany) for a two-tailed independent-samples t-test comparing two groups. Based on effect sizes reported in comparable suspension-training and corrective-exercise trials for lower-limb and core outcomes, a large effect size (Cohen's d = 1.0) was assumed a priori. With $\alpha = 0.05$ and power $(1-\beta) = 80\%$, this calculation indicated a minimum of 17 participants per group. This figure was rounded up to

18 participants per group (36 total) to allow for an anticipated dropout rate of approximately 10%; in the event, no participants were lost to follow-up.

Inclusion Criteria

Male college-level cricket players aged 18-25 years with a clinical diagnosis of LCS who provided written informed consent.

Exclusion Criteria

A history of acute musculoskeletal injury within the preceding six months, a neurological or systemic condition affecting posture or movement, prior experience with TRX training or structured core rehabilitation or any contraindication to physical activity or suspension-based exercise.

Randomization and Allocation

A computer-generated randomization sequence (permuted block randomization, block size of 4) was produced in Microsoft Excel by an independent statistician who had no involvement in recruitment, intervention delivery or outcome assessment. The allocation sequence was concealed using sequentially numbered, opaque, sealed envelopes (SNOSE) prepared in advance of recruitment. Each envelope was opened only after a participant's baseline assessment was complete by an independent co-investigator who was not involved in outcome assessment; this individual assigned participants to Group 1 (TRX, n = 18) or Group 2 (CE, n = 18) according to the concealed sequence. Outcome assessors administering the SRT, DLLT and SLGBT remained blinded to group allocation throughout the study and participants were asked not to disclose their assigned intervention to the assessors. Because of the physical nature of the interventions, blinding of participants and treating therapists was not feasible.

Intervention Protocol

Following baseline testing (Week 0), Group 1 undertook a structured TRX program while Group 2 completed conventional exercise comprising static stretching and traditional core-strengthening movements. Both groups trained three times weekly for six weeks, with sessions lasting approximately 50 minutes. Reassessment took place at Week 3 and Week 6. Full protocol details appear in Table 1. The supervising therapists recorded session attendance at every training session and treatment fidelity was supported by standardized, protocol-driven exercise progression applied identically to all participants. At each visit, participants were also asked to report any exercise activity undertaken outside supervised sessions, allowing outside-session adherence to be monitored alongside in-session attendance.

Group 1: Total Resistance Exercise (TRX) Program

The TRX program consisted of suspension-based, closed-kinetic-chain exercises targeting core strength, flexibility

Table 1: Exercise Training Protocol for the TRX and Conventional Exercise Groups

Parameter	Group 1-TRX	Group 2-CE
Programme name	Total Resistance Exercise (TRX) Training	Conventional Core & Flexibility Training
Exercise type	Suspension-based closed-kinetic-chain exercises targeting core, flexibility and stability	Static stretching and traditional core-strengthening exercises
Exercises	Pike crunch on hands; mountain climber; oblique crunch; lunge; plank; hamstring curl; squat	Crunches; bridges; leg raises; static hamstring stretch; hip flexor stretch; prone press-up
Progression	Week 1-2: 2×9 reps/9 s; Week 3: 2×12; Week 4: 2×15; Week 5: 3×15; Week 6: 2×9 (deload)	Progressive increase matched with the TRX group across 6 weeks
Rest period	30 s between exercises; 2-3 min between sets	30 s between exercises; 2-3 min between sets
Warm-up	Running-15 minutes	Running-15 minutes
Frequency	3 sessions/week (Saturday, Monday, Wednesday)	3 sessions/week (Saturday, Monday, Wednesday)
Session duration	~50 minutes	~50 minutes
Programme duration	6 weeks	6 weeks
Assessment points	Week 0 (baseline), Week 3, Week 6	Week 0 (baseline), Week 3, Week 6

TRX: Total Resistance Exercise, CE: Conventional Exercise and stability: Pike crunch on hands, mountain climber, oblique crunch, lunge, plank, hamstring curl and squat. This design was chosen because TRX suspension training has been reported to improve core strength and stability in young athletes meaningfully [9] and electromyographic evidence indicates that TRX exercises elicit greater paraspinal and abdominal activation than equivalent exercises performed on a stable surface, supporting their use for lumbopelvic rehabilitation [10].

Training load progressed from two sets of nine repetitions (nine-second holds) in Weeks 1-2, to two sets of 12 in Week 3, two sets of 15 in Week 4, three sets of 15 in Week 5, before a deload of two sets of nine in Week 6. Rest intervals were 30 seconds between exercises and 2-3 minutes between sets, with a 15-minute run as a warm-up before each session.

Group 2: Conventional Exercise (CE) Program

Group 2 performed conventional core and flexibility training: Crunches, bridges, leg raises, static hamstring stretch, hip flexor stretch and prone press-up.

Training volume progressed to match the TRX group across the six weeks, using the same rest intervals, warm-up and weekly schedule. All sessions in both groups were supervised on a one-to-one basis by qualified physiotherapists trained in the study protocol, with supervision consistency maintained by having the same therapist oversee a given participant across all six weeks wherever possible.

Outcome Measures

Sit and Reach Test (SRT). The SRT gauges the extensibility of the hamstrings and lumbar region [11]. Participants sat with legs fully extended and reached forward as far as possible along a standardized scale; the mean of three trials, in centimeters, was recorded.

Double Leg Lowering Test (DLLT). Kinematic evidence indicates that early anterior pelvic tilt during leg lowering reflects the quality of posterior pelvic tilt motor control [12] and the DLLT has demonstrated excellent intra-tester reliability (ICC = 0.98) for assessing abdominal muscle performance and lumbopelvic stability [13]. A pressure biofeedback cuff was placed beneath the lumbar spine and inflated to 40 mmHg. Participants lowered both legs from 90° of hip flexion and the angle at which the lumbar spine lost contact with the cuff was recorded; lower angles reflect greater lumbopelvic stability and motor control.

Single Leg Glute Bridge Test (SLGBT). The SLGBT measures unilateral gluteal strength and endurance, recorded as the number of seconds a participant could sustain a single-leg bridge position. Together, these three measures were selected to capture the flexibility, lumbopelvic stability and gluteal endurance deficits characteristic of LCS in a cricket-specific population, consistent with prior evaluations of lumbar core stability among club-level cricket bowlers [14]. Established Minimal Clinically Important Difference (MCID) values for the SRT, DLLT and SLGBT in this specific population have not been established in the literature; nevertheless, the between-group differences observed at Week 6 (SRT 3.94 cm, DLLT -9.63°, SLGBT 14.57 s) exceed the typical measurement error reported for these tests, suggesting that the improvements are likely to be clinically as well as statistically meaningful.

Statistical Analysis

Data were analyzed using repeated-measures ANOVA (general linear model) to compare within-group and between-group change across the three assessment points (Week 0, Week 3, Week 6). The Shapiro-Wilk test confirmed normal distribution prior to analysis. Between-group mean differences at each time point were further characterized using independent-samples t-tests, with 95% confidence intervals and Cohen's d (pooled-standard-deviation) effect sizes calculated for each comparison. Statistical significance was set at $p<0.05$ and all calculations were performed in SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Mauchly's test of sphericity was applied to each repeated-measures ANOVA; where the assumption of sphericity was violated, Greenhouse-Geisser correction was used to adjust the degrees of freedom and partial eta-squared (η^2) was calculated as a measure of effect size for each ANOVA to complement the between-group Cohen's d values. Sphericity was violated for all three outcomes (Mauchly's W = 0.019 for SRT, 0.0011 for DLLT and <0.001 for SLGBT; all $p<0.001$); Greenhouse-Geisser-corrected degrees of freedom (ε = 0.53-0.54) were therefore applied to the time and Group×Time effects. Partial eta-squared for the Group×Time interaction was 0.65 (SRT), 0.94 (DLLT) and 0.97 (SLGBT), indicating very large effects for all three outcomes.

RESULTS

Participant Flow

Sixty prospective participants were screened for eligibility. Twenty-four were excluded-18 for not meeting the inclusion criteria, four who declined to participate and two for other reasons-leaving 36 players who were randomized into Group 1 (TRX, n = 18) and Group 2 (CE, n = 18). All 36 participants received their allocated intervention and none were lost to follow-up at Week 3 or Week 6. No participant discontinued the intervention and all 36 were included in the final analysis of the three outcome measures (SRT, DLLT, SLGBT). The complete flow of participants through the trial is shown in Figure 1.

Baseline Characteristics

Baseline scores for the SRT, DLLT and SLGBT were statistically comparable between the two groups ($p>0.05$), confirming that randomization produced balanced groups at the outset (Figure 2).

Both groups showed statistically significant improvement on all three outcome measures at every time point (mixed-design ANOVA, main effect of time $p<0.001$ for all outcomes; Table 2). Group 1 (TRX) achieved

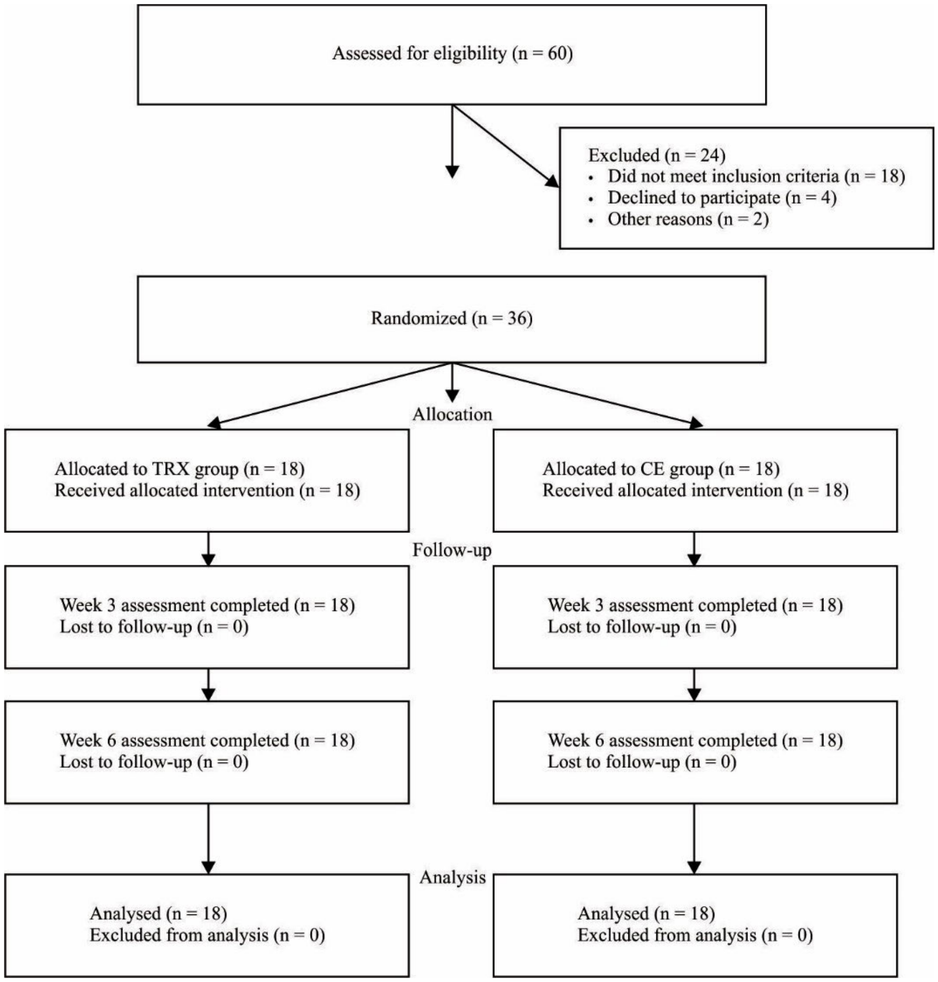

Figure 1: CONSORT Flow Diagram of Participant Recruitment, Allocation, Follow-Up and Analysis

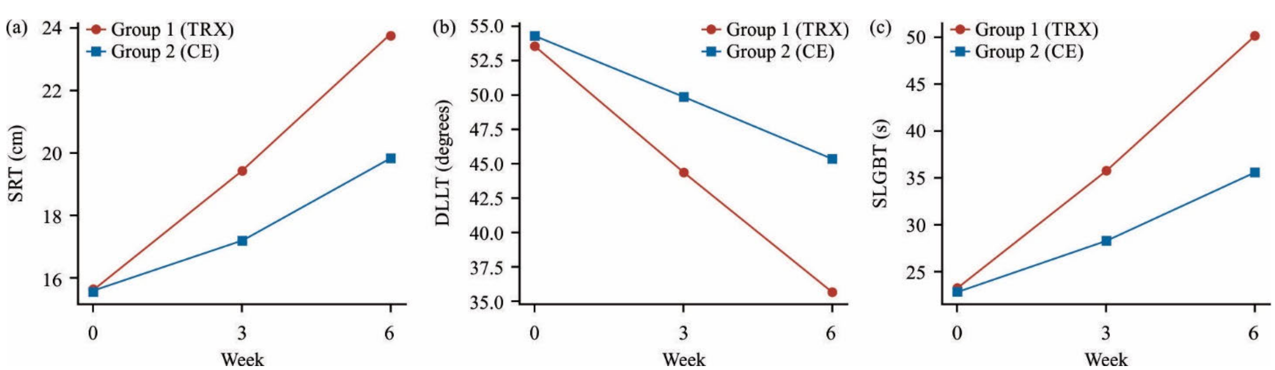

Figure 2: Change in Sit and Reach Test, Double Leg Lowering Test and Single Leg Glute Bridge Test scores across Week 0, Week 3 and Week 6 for Group 1 (TRX) and Group 2 (CE)

significantly larger gains than Group 2 (CE) on all three outcome measures-SRT, DLLT and SLGBT-reflecting a consistent advantage for TRX rather than differential effects across outcomes, with large Group×Time interaction effects (partial η^2 0.65-0.97; Table 2). Detailed results, including between-group mean differences, 95% confidence intervals, exact P-values, percentage improvement from baseline and Cohen's d effect sizes, appear in Table 3-5. The between-group Cohen's d values for SLGBT (5.01) and DLLT (-3.71) at Week 6 remain large by conventional standards; this reflects the tight clustering of standard deviations in this sample and the values should be interpreted with corresponding caution, as discussed further in the Limitations section.

Between-group differences favoring Group 1 (TRX) were significant at Week 3 (2.90 cm, 95% CI 1.92-3.88,

Table 2: Summary of Between-Group Comparisons Across All Outcome Measures

Outcome	Week	Group 1-TRX (Mean±SD)	Group 2-CE (Mean±SD)	Mean Diff.	95% CI	Cohen's d	p-value
Sit & Reach (cm)	0	15.37±1.64	15.46±1.40	-0.09	-1.12, 0.94	-0.06	0.862
Sit & Reach (cm)	3	21.41±1.59	18.51±1.29	2.90	1.92, 3.88	2.00	<0.001 (8.73×10^{-7})
Sit & Reach (cm)	6	23.67±1.65	19.35±1.53	4.32	3.24, 5.39	2.72	<0.001 (1.60×10^{-9})
DLLT (degrees)	0	53.49±1.64	54.26±1.39	-0.76	-1.79, 0.27	-0.50	0.142
DLLT (degrees)	3	44.32±1.69	49.88±1.52	-5.57	-6.65, -4.48	-3.47	<0.001 (4.28×10^{-12})
DLLT (degrees)	6	39.89±1.52	46.84±2.17	-6.96	-8.23, -5.69	-3.71	<0.001 (7.14×10^{-13})
SLGBT (seconds)	0	23.14±1.78	22.81±1.32	0.33	-0.73, 1.40	0.21	0.529
SLGBT (seconds)	3	35.72±2.64	28.21±1.76	7.52	6.00, 9.03	3.36	<0.001 (9.86×10^{-12})
SLGBT (seconds)	6	50.09±3.44	35.49±2.27	14.60	12.63, 16.57	5.01	<0.001 (1.39×10^{-16})
Sit & Reach (cm)	% Δ Baseline (Week 3/ Week 6)	+39.3% / +54.0%	+19.7% / +25.1%	-	-	-	-
DLLT (degrees)	% Δ Baseline (Week 3/ Week 6)	-17.2% / -25.4%	-8.1% / -13.7%	-	-	-	-
SLGBT (seconds)	% Δ Baseline (Week 3/ Week 6)	+54.3% / +116.4%	+23.6% / +55.6%	-	-	-	-

DLLT: Double Leg Lowering Test, SLGBT: Single Leg Glute Bridge Test, CE: Conventional Exercise, TRX: Total Resistance Exercise, CI: confidence interval, Cohen's d calculated from pooled standard deviations (independent-samples convention), Values ≥0.8 are conventionally interpreted as large

Table 3: Sit and Reach Test (cm): Between-Group Comparison Across Three Time Points

Week	Group 1-TRX (Mean±SD)	Group 2-CE (Mean±SD)	Mean Diff.	95% CI	Cohen's d	p-value
0 (Baseline)	15.37±1.64	15.46±1.40	-0.09	-1.12, 0.94	-0.06	0.862
3	21.41±1.59	18.51±1.29	2.90	1.92, 3.88	2.00	<0.001 (8.73×10^{-7})
6	23.67±1.65	19.35±1.53	4.32	3.24, 5.39	2.72	<0.001 (1.60×10^{-9})
% Δ Baseline (Week 3/Week 6)	+39.3% / +54.0%	+19.7% / +25.1%	-	-	-	-

Table 4: Double Leg Lowering Test (degrees): Between-Group Comparison Across Three Time Points

Week	Group 1-TRX (Mean±SD)	Group 2-CE (Mean±SD)	Mean Diff.	95% CI	Cohen's d	p-value
0 (Baseline)	53.49±1.64	54.26±1.39	-0.76	-1.79, 0.27	-0.50	0.142
3	44.32±1.69	49.88±1.52	-5.57	-6.65, -4.48	-3.47	<0.001 (4.28×10^{-12})
6	39.89±1.52	46.84±2.17	-6.96	-8.23, -5.69	-3.71	<0.001 (7.14×10^{-13})
% Δ Baseline (Week 3/ Week 6)	-17.2% / -25.4%	-8.1% / -13.7%	-	-	-	-

Table 5: Single Leg Glute Bridge Test (Seconds): Between-Group Comparison Across Three Time Points

Week	Group 1-TRX (Mean±SD)	Group 2-CE (Mean±SD)	Mean Diff.	95% CI	Cohen's d	p-value
0 (Baseline)	23.14±1.78	22.81±1.32	0.33	-0.73, 1.40	0.21	0.529
3	35.72±2.64	28.21±1.76	7.52	6.00, 9.03	3.36	<0.001 (9.86×10^{-12})
6	50.09±3.44	35.49±2.27	14.60	12.63, 16.57	5.01	<0.001 (1.39×10^{-16})
% Δ Baseline (Week 3/ Week 6)	+54.3% / +116.4%	+23.6% / +55.6%	-	-	-	-

d = 2.00, p<0.001; exact $p = 8.73\times10^{-7}$) and Week 6 (4.32 cm, 95% CI 3.24-5.39, d = 2.72, p<0.001; exact $p = 1.60\times10^{-9}$). From baseline to Week 6, Group 1 (TRX) improved by 54.0% and Group 2 (CE) by 25.1% (see % Change row in Table 3).

Lower angles indicate greater lumbopelvic stability. Group 1 (TRX) showed significantly better (lower) values than Group 2 (CE) at Week 3 (-5.57°, 95% CI -6.65 to -4.48, d = -3.47, p<0.001; exact $p = 4.28\times10^{-12}$) and Week 6 (-6.96°, 95% CI -8.23 to -5.69, d = -3.71, p<0.001; exact $p = 7.14\times10^{-13}$). From baseline to Week 6, Group 1 (TRX) improved by 25.4% and Group 2 (CE) by 13.7% (see % Change row in Table 4).

Group 1 (TRX) showed significantly greater gluteal endurance at Week 3 (7.52 s, 95% CI 6.00-9.03, d = 3.36, p<0.001; exact $p = 9.86\times10^{-12}$) and Week 6 (14.60 s, 95% CI 12.63-16.57, d = 5.01, p<0.001; exact $p = 1.39\times10^{-16}$). From baseline to Week 6, Group 1 (TRX) improved by 116.4% and Group 2 (CE) by 55.6% (see % Change row in Table 5).

Mixed-design (Group×Time) ANOVA: Sphericity was violated for all three outcomes (Mauchly's W: SRT = 0.019, DLLT = 0.0011, SLGBT<0.001; all p<0.001), so Greenhouse-Geisser-corrected degrees of freedom were used (ε = 0.53-0.54). Group×Time interaction effects were large for all outcomes: partial $\eta^2 = 0.65$ (SRT), 0.94 (DLLT), 0.97 (SLGBT); all p<0.001.

Summary of Findings

Both TRX and conventional exercise produced statistically significant within-group gains in flexibility and core strength across the six-week program.

TRX conferred a significant advantage over conventional exercise on all three outcome measures-hamstring/lumbar flexibility, lumbopelvic stability and gluteal endurance-rather than the split pattern of relative strengths originally hypothesized.

DISCUSSION

Both TRX and conventional exercise led to statistically significant gains in flexibility and core strength among college-level cricket players with LCS. TRX produced significantly better outcomes than CE on all three measures-hamstring flexibility (SRT), lumbopelvic stability (DLLT) and gluteal endurance (SLGBT)-a consistent advantage that likely reflects the greater neuromuscular and proprioceptive demand of suspension-based training relative to floor-based conventional exercise. Beyond statistical significance, these gains appear clinically meaningful: participants moved from below-normative baseline scores toward values consistent with functional flexibility, lumbopelvic control and gluteal endurance, changes that plausibly translate into reduced low back pain and improved on-field movement quality for cricketers with LCS and this clinical dimension should be weighted at least as heavily as the statistical results when judging the value of either intervention.

Physiological Mechanisms Underlying TRX's Superior Training Adaptations

The between-group differences observed in this trial likely reflect distinct neuromuscular and biomechanical demands imposed by suspension-based versus floor-based training, consistent with established models of spinal stability that emphasize motor control across a functional neutral zone rather than strength considered in isolation. TRX exercises are performed on an unstable suspension apparatus, which increases the postural challenge of every movement and requires continuous neuromuscular activation to maintain trunk and limb alignment throughout the range of motion. This instability-induced motor unit recruitment is thought to engage a broader pool of stabilizing musculature, including the deep trunk stabilizers and hip girdle muscles, than equivalent exercises performed on a stable surface. The suspended, semi-unstable base also increases proprioceptive demand: constant micro-adjustments at the ankle, knee, hip and trunk are required to control the moving suspension straps, which may help explain the superior gains in gluteal endurance (SLGBT) and flexibility (SRT) observed in the TRX group. This repeated proprioceptive challenge is known to enhance both muscular endurance and dynamic flexibility. TRX movements such as the plank, mountain climber and pike crunch also load the posterior and lateral fascial chains-particularly the posterior oblique and lateral slings-promoting multi-planar loading that may contribute to the greater hamstring and lumbar extensibility seen on the SRT. Finally, because TRX exercises are inherently closed-kinetic-chain movements performed with the distal segment fixed to the suspension straps, they impose adaptations that emphasize co-contraction of agonist-antagonist muscle pairs around the hip and trunk, a pattern that may be particularly effective for re-educating the gluteal inhibition characteristic of LCS. The same instability-driven demand for continuous trunk bracing likely also explains TRX's advantage on the DLLT: Maintaining alignment on a moving suspension system requires sustained anticipatory activation of the deep abdominal and posterior pelvic tilt musculature, a more demanding stimulus for lumbopelvic motor control than the fixed base of support used in the floor-based CE program.

These findings align with a broader body of evidence indicating that syndrome-specific corrective exercise outperforms generalized training for postural dysfunction. A randomized comparison of specific versus generalized treatment protocols for LCS found that targeted programs produced significantly greater correction of the underlying muscle imbalance than non-specific exercise [15], supporting the rationale for prescribing structured, LCS-directed protocols such as those used in this trial rather than generic conditioning. Core stability-based corrective exercise has similarly improved gait parameters in athletes with middle crossed syndrome, indicating that the benefits of targeted corrective training extend beyond the lumbopelvic region to other presentations along the same crossed-syndrome spectrum [16]. Direct comparisons of core-stability and NASM-based corrective protocols for LCS have reported that both approaches produce meaningful, though not identical, improvements depending on the outcome assessed [17], a pattern that differs from the uniform TRX advantage observed across all outcomes in the present trial, in which TRX outperformed CE on every measure rather than showing outcome-specific relative strengths.

The advantage seen with TRX on the SRT fits with the established profile of LCS, in which tight hip flexors and lumbar extensors are considered primary drivers of increased lumbar lordosis and chronic low back pain. Because TRX exercises are performed in suspension, they promote multi-planar stretching and eccentric loading of the posterior chain, which likely improves hamstring extensibility and lumbar flexibility. This is consistent with earlier findings that TRX suspension training enhances core strength and stability in young athletes, as well as with interventional evidence that suspension-based programs improve both static and dynamic balance [18].

These findings carry particular relevance for cricket, where LCS can hinder the repetitive, asymmetrical movements of bowling, batting and fielding. A smaller lumbar multifidus cross-sectional area has been identified as a risk factor for low back injury in fast bowlers and structured conditioning has previously improved power, speed and endurance in elite cricketers. Comparable cricket-specific training research has shown that combined power- and complex-training approaches meaningfully improve core, lower-limb and upper-limb strength in male cricketers [19], underscoring that targeted, sport-relevant conditioning of the kind trialed here can be expected to transfer to on-field performance and injury resilience.

The markedly larger SLGBT gain in the TRX group (14.60 s at Week 6, $p<0.001$) points to TRX's capacity to build gluteal endurance and neuromuscular activation. Gluteal inhibition, driven by reciprocal inhibition from overactive hip flexors, is a key feature of LCS-related dysfunction. TRX movements such as the lunge, squat and hamstring curl demand sustained gluteal engagement, offering a functional stimulus for gluteal re-education that floor-based exercise may not replicate as effectively. This pattern mirrors evidence that suspension training produces greater gains in postural stability, lumbopelvic control and proprioception than isometric-isotonic floor-based training [20] and that structured TRX programs meaningfully improve lower-extremity alignment and muscle strength [21]. Biomechanical modeling further shows that hip-focused, closed-kinetic-chain exercises generate substantial gluteus maximus and medius forces [22], offering a mechanistic explanation for the superior gluteal endurance observed in the TRX group here.

The larger DLLT improvement seen in the TRX group in this trial suggests that suspension-based training also engages the abdominal musculature and posterior pelvic tilt mechanism effectively-and, in this sample, more effectively than the floor-based CE program. The DLLT's strong reliability (ICC = 0.98) makes it a sensitive measure of lower abdominal function; the instability inherent to TRX training may impose a greater demand on anticipatory trunk control than the fixed base of support used in CE, offering one explanation for TRX's advantage on this measure. Comparative studies of NASM-based and core-stability corrective approaches in athletes with LCS have reported meaningful improvements in lumbar lordosis angle, pelvic tilt and trunk muscle endurance with both approaches [23] and trials of Janda's and Sahrmann's corrective exercise approaches have likewise confirmed restoration of muscle balance and postural improvement in LCS with floor-based work [24]-indicating that while CE remains a valid rehabilitation option, TRX's added instability component appears to confer a further advantage for lumbopelvic control in this population.

Protocol-based suspension-training studies have also reported reduced low back pain and improved musculoskeletal function following structured programs [25], supporting TRX's broader role as a rehabilitation tool for athletes and lending confidence that the gains observed in this trial are likely to translate into meaningful functional benefit for cricketers with LCS.

Strengths of the Study

This trial has several notable strengths. Its randomized, CONSORT-guided design, a priori sample-size calculation and blinded outcome assessment reduce the risk of selection and detection bias. Both groups followed standardized, supervised protocols delivered on an identical schedule, supporting consistent intervention delivery. Three outcome measures-the SRT, DLLT and SLGBT-were used to capture flexibility, lumbopelvic stability and gluteal endurance, giving a broad picture of core and flexibility outcomes. The head-to-head comparison between TRX and conventional exercise also provides clinicians with practical evidence for selecting a rehabilitation approach for cricketers with LCS.

CONCLUSIONS

Both TRX and conventional exercise produced meaningful gains in flexibility and core strength among college-level cricket players with LCS but TRX produced significantly greater improvement than conventional exercise on every outcome measured-hamstring flexibility, lumbopelvic stability and gluteal endurance. These findings indicate that TRX, rather than conventional exercise alone, is the more effective rehabilitation approach for LCS in this athletic population. Whether combining TRX with conventional-exercise elements offers any incremental benefit over TRX alone was not tested in the present trial and remains a hypothesis for future confirmatory research.

Clinical Implications

These findings support TRX as the preferred rehabilitation approach for college-level cricket players with LCS, having outperformed conventional exercise on flexibility, lumbopelvic stability and gluteal endurance alike. It should be emphasized that this evidence base remains limited to young, male, college-level cricketers and implementation recommendations should be framed accordingly until confirmed in broader populations. Conventional core exercise still produced meaningful within-group gains and may remain a reasonable option where TRX equipment or supervision is unavailable but where feasible, TRX should be prioritized. Whether adding conventional exercise elements to a TRX program yields any incremental benefit over TRX alone was not tested here and remains an open question for future research rather than a basis for a current combined-protocol recommendation.

Future Recommendations

Future research should involve larger, multi-center samples of both male and female cricketers across a range of competitive levels, incorporate a no-treatment control arm and extend follow-up beyond six weeks to establish whether gains are maintained over time. Given that TRX outperformed CE on every outcome in this trial, future trials should also test whether adding conventional-exercise elements to a TRX program provides any incremental benefit over TRX alone. Biomechanical or electromyographic assessment would help clarify the neuromuscular mechanisms underlying TRX's advantage over conventional exercise observed in this trial.

Limitations

The sample was restricted to male college-level cricket players, which limits generalisability to female athletes or other competitive levels. The intervention lasted only six weeks and no longer-term follow-up was conducted to confirm whether the observed gains were sustained. The absence of a no-treatment control arm means the contribution of natural recovery cannot be fully excluded. The pooled-SD effect sizes for several comparisons were very large (e.g., Cohen's d exceeding 3 for the DLLT and SLGBT at Week 6); this reflects the tightly clustered standard deviations reported in this sample and should be interpreted with some caution, as variability of this magnitude is uncommon in field-based exercise trials. Because participants and treating therapists could not be blinded to group allocation, performance bias cannot be excluded and the awareness of being observed may have contributed a Hawthorne effect to the within-group improvements seen in both arms. The trial also lacked objective imaging or biomechanical assessment (e.g., ultrasound or electromyography) to corroborate the functional test findings. Ethics committee identification details are reported in the Ethical Approval section above (Institutional Scientific Review Board, Approval No. 044/05/2025/ISRB/PGSR/SCPT) and are no longer pending.

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Conflicts of Interest

The authors declare no conflicts of interest with any financial organization in relation to the material discussed in this manuscript.

Ethical Approval

The study was approved by the Institutional Scientific Review Board (Approval No: 044/05/2025/ISRB/PGSR/SCPT).

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