

Predictive Value of a Composite Multi-Domain Screening Battery in Identifying Non-Contact Lower Limb Injury Risk Among Recreational Athletes: A Prospective Cohort Study

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Abstract- Background: Non-contact lower limb injuries are the dominant cause of sports-related musculoskeletal morbidity in recreational athletes globally. The Functional Movement Screen (FMS), the most widely adopted screening tool, shows inconsistent standalone predictive validity, partly because it fails to assess neuromuscular control, dynamic postural stability, or inter-limb asymmetry — domains independently implicated in injury pathomechanics.

Objectives: (1) To determine whether a composite multi-domain battery (FMS + neuromuscular battery + Y Balance Test) provides superior predictive accuracy for non-contact lower limb injury risk versus FMS alone; (2) to identify independent injury predictors; and (3) to establish a three-tier risk stratification framework.

Methods: N = 83 recreational athletes (mean age 26.4 ± 4.8 years) enrolled at PhysioChiroNexus branches across Bangalore. All completed FMS, a four-test neuromuscular battery (SLST, SDT, SLHT, DJLT-LESS), and bilateral YBT at baseline (January–February 2024). Six-month weekly injury surveillance followed (February–August 2024). Binary logistic regression, DeLong's ROC comparison, and Kaplan–Meier analysis performed using IBM SPSS v26.0.

Results: Twenty-seven athletes (32.5%) sustained 31 non-contact injuries. Composite battery AUC = 0.924 (95% CI: 0.868–0.980), significantly superior to FMS alone (AUC = 0.742; DeLong's $z = 3.42$, $P = .001$). YBT composite score was the strongest predictor (OR = 22.29). Clear dose–response: 74.2% injury incidence in high-risk vs. 14.3% moderate-risk vs. 0.0% low-risk (Fisher's exact $P < .001$).

Conclusions: A composite multi-domain screening battery significantly outperforms FMS alone. The three-

tier stratification (0/1/≥2 positive domains) provides a clinically actionable framework for pre-participation risk stratification. Level of Evidence: Level II.

Keywords: Functional Movement Screen; neuromuscular control; Y Balance Test; lower limb injury; recreational athletes; prospective cohort; ROC analysis; Kaplan–Meier; sports physiotherapy

I. INTRODUCTION

1.1 Epidemiology and Global Burden

Non-contact lower limb injuries — encompassing anterior cruciate ligament (ACL) sprains, lateral ankle ligament complex injuries, hamstring muscle strains, patellofemoral pain syndrome (PFPS), iliotibial band syndrome, patellar tendinopathy, and stress fractures — collectively account for 50–70% of all sports-related musculoskeletal injuries presenting to primary care and sports medicine clinics globally.¹ The global recreational athletic population exceeds 1.2 billion individuals engaged in structured physical activity ≥3 sessions per week; unlike elite athletes who access systematic medical support, recreational athletes rarely undergo pre-participation musculoskeletal screening, rendering them disproportionately vulnerable to preventable injury events.² In India, surveys across Bangalore's recreational sporting community reveal annual lower limb injury incidence rates of 28–42 per 100 athletes, with 62% of injuries classified as non-contact in mechanism — emphasising the preventable nature of the majority of sports-related morbidity in this population.

1.2 Risk Factors for Non-Contact Lower Limb Injury

The aetiology of non-contact lower limb injury is multifactorial, with evidence supporting the following principal risk factor domains:

Intrinsic Biomechanical Risk Factors: Dynamic knee valgus during landing and cutting tasks — defined as combined hip adduction, hip internal rotation, and tibial abduction — generates ACL strain magnitudes exceeding 200% of the ligament's in-situ force threshold.³ Anterior pelvic tilt and reduced hip extensor activation shift compressive loading anteriorly, elevating patellofemoral joint reaction forces by 40–60%.⁴ Inter-limb asymmetry in hop performance exceeding 10–15% (limb symmetry index <85–90%) independently predicts re-injury risk.⁵

Neuromuscular Control Deficits: Deficient pre-activation of the hamstrings and gluteus medius prior to ground contact results in inadequate co-contraction protection for the ACL during eccentric loading phases.⁶ Delayed peroneal reaction time (>65 ms) is strongly associated with ankle inversion injury recurrence. Proprioceptive accuracy deficits — quantified by joint position sense error and threshold to detection of passive movement — reduce anticipatory postural adjustment amplitude, compromising reactive stabilisation capacity.⁷

Dynamic Postural Control Deficits: YBT composite reach scores below 94% of limb length confer a 6.5-fold increase in injury risk (OR=6.5; 95% CI: 3.0–14.5).⁸ Anterior reach asymmetry exceeding 4 cm between limbs is associated with 2.5-fold greater ankle sprain risk. Single-leg squat performance deficits correlate with hip abductor weakness and predict PFPS development.⁹

Landing Biomechanics: LESS scores ≥ 5 indicate aberrant landing mechanics associated with 3.5-fold greater ACL injury risk.¹⁰ Peak ground reaction force, knee flexion angle at initial contact, and trunk flexion angle collectively explain 72% of variance in ACL strain during jump-landing tasks.

Modifiable Extrinsic Factors: Training load errors (>10% weekly progression), inadequate warm-up protocols, surface type, footwear mismatch, and psychosocial stressors (poor sleep, high anxiety) further modulate injury risk through neuro-endocrine pathways that reduce neuromuscular response accuracy.¹¹

1.3 Pathomechanics of Non-Contact Lower Limb Injury

The neuromuscular pathomechanical cascade of non-contact lower limb injury follows a consistent sequence across injury subtypes. During high-velocity cutting, jumping, or change-of-direction tasks, the following sequence has been characterised by prospective motion-capture analyses: (1) Initial contact in relative knee extension (flexion angle <30°) with hip in adduction — reducing the mechanical advantage of the quadriceps and maximising anterior tibial shear force; (2) Dynamic valgus collapse driven by gluteus medius and external hip rotator co-activation failure — concentrating compressive and rotatory loads on medial and anterior knee structures; (3) Trunk contralateral lean or excessive forward lean — shifting the ground reaction force vector anterior to the knee joint, further loading the ACL; (4) Plantarflexed ankle at initial contact — increasing ground reaction force peak rate of loading and reducing the shock attenuation contribution of the gastrocnemius–soleus complex.¹²

For ankle sprain pathomechanics: sudden inversion-plantarflexion loading occurs in <40 ms — faster than the 65–100 ms electromechanical delay of the peroneus longus, making reactive muscular protection mechanically impossible without anticipatory pre-activation. This pre-activation is governed by cerebellar feedforward motor programmes dependent on intact proprioceptive afference from ankle mechanoreceptors — disrupted by prior sprain-associated mechanoreceptor loss.¹³ For hamstring strains, eccentric overloading during late swing phase of sprinting — when the hamstring simultaneously generates peak force and achieves maximum length — exceeds the muscle-tendon unit's failure threshold when neuromuscular fatigue has reduced eccentric force capacity.

1.4 Limitations of Existing Screening Tools

The Functional Movement Screen (FMS), developed by Cook, Burton, and Hoogenboom,¹⁴ evaluates seven fundamental movement patterns on a 0–3 ordinal scale (composite 0–21). Despite adoption by >40,000 practitioners worldwide, three systematic reviews and meta-analyses^{15–17} have identified inconsistent standalone predictive validity (pooled AUC range: 0.58–0.72; sensitivity 39–67%). This inconsistency is mechanistically explicable: FMS does not quantify

neuromuscular activation timing, dynamic multiplanar balance, limb symmetry, or landing biomechanics — the four domains independently most strongly associated with injury pathomechanics.

The YBT, while demonstrating stronger predictive validity (AUC 0.75–0.85),⁸ evaluates dynamic balance in isolation and cannot detect FMS-captured movement quality deficits or neuromuscular pre-activation deficits quantified by the SLST and DJLT. Single-domain assessment therefore captures only a fraction of the injury risk landscape, explaining the persistently unacceptably high non-contact injury rates despite widespread single-tool screening adoption.

1.5 Review of Literature

Kiesel et al¹⁸ (2007) were among the first to demonstrate prospective FMS predictive validity in NFL players (FMS ≤ 14 : OR=11.67 for serious injury). Plisky et al⁸ (2006) established YBT anterior reach asymmetry >4 cm as a significant ankle sprain predictor in high school basketball players (OR=2.5). Padua et al¹⁰ (2009) validated the LESS as a reliable and valid landing biomechanics assessment tool (ICC=0.91; sensitivity=85% for high-risk landing patterns). Moran et al¹⁵ (2017) reviewed 17 studies and concluded FMS ≤ 14 carries LR+ of only 1.98, insufficient for confident individual risk stratification without additional assessment domains. Bonazza et al¹⁶ (2017) similarly found FMS composite score had poor-to-moderate predictive value across 24 studies (AUC range 0.47–0.74).

Composite or multi-domain screening approaches have been advocated theoretically by Meeuwisse's dynamic model of sport injury aetiology¹⁹ and the Van Mechelen sequence of prevention framework.²⁰ However, no prospective cohort study has empirically validated a pre-specified multi-domain composite battery against injury outcomes in recreational athletes in an Indian clinical context. The present study at PhysioChiroNexus branches across Bangalore addresses this critical evidence gap.

1.6 Objectives

Primary Objective: To compare the predictive accuracy (AUC) of a composite multi-domain screening battery (FMS + neuromuscular battery + YBT) versus FMS alone for non-contact lower limb injury over a 6-month prospective cohort in recreational athletes.

Secondary Objectives: (1) To identify independent predictors of non-contact injury using multivariate binary logistic regression; (2) To establish and validate a three-tier composite risk stratification algorithm (low / moderate / high risk); (3) To quantify injury-free survival time across risk tiers using Kaplan–Meier analysis.

1.7 Aims

(1) To screen N=83 recreational athletes at PhysioChiroNexus branches across Bangalore using the composite battery at baseline; (2) To conduct weekly injury surveillance over 6 months (February–August 2024); (3) To determine AUC, sensitivity, specificity, PPV, NPV, and LR+ for all screening approaches; (4) To provide an evidence-based recommendation on optimal pre-participation screening protocol for community sports physiotherapy practice in India.

II. METHODS

2.1 Study Design, Setting, and Registration

Prospective observational cohort study (STROBE-compliant). January 2024 – August 2024 (8 months; 6-month prospective follow-up). All participants assessed and treated at PhysioChiroNexus – Advanced Physiotherapy & Chiropractic Care Clinic, branches in and around Bangalore (Sarjapur Road, Varthur, Whitefield, HSR Layout, Electronic City, Koramangala). Prospectively registered: ClinicalTrials.gov NCT06284761 | CTRI/2024/01/081943. Ethics: IEC-PCN-2024-001. Written informed consent in English or Kannada.

2.2 Inclusion Criteria

(1) Age 18–35 years, male or female; (2) Recreational athlete engaged in structured sporting activity ≥ 3 sessions/week for ≥ 3 consecutive months at time of enrolment; (3) Sports with directional change, jumping, or running demand (football, basketball, badminton, volleyball, cricket, athletics, gym-based HIIT); (4) Free of acute musculoskeletal injury at time of baseline assessment; (5) Able to complete all three battery components without pain restriction; (6) Resident within PhysioChiroNexus catchment area (Bangalore and surrounding districts); (7) Ability to provide informed consent and complete weekly online surveillance.

2.3 Exclusion Criteria

(1) Acute lower limb musculoskeletal injury (pain >3/10 NRS) in the preceding 3 months; (2) Lower limb surgical intervention within 12 months prior to enrolment; (3) Diagnosed neurological condition affecting balance or motor control (peripheral neuropathy, vestibular disorder, cerebellar ataxia, stroke sequelae); (4) Systemic inflammatory arthropathy (rheumatoid arthritis, ankylosing spondylitis, psoriatic arthritis) or connective tissue disorder; (5) Active malignancy or metabolic bone disease; (6) Pregnancy or current lactation; (7) Concurrent participation in another musculoskeletal intervention trial; (8) Inability or unwillingness to

complete weekly online injury surveillance for 6 months; (9) BMI >40 kg/m² (limiting movement quality assessment validity).

2.4 Composite Risk Classification

Three binary domain criteria pre-specified prior to data collection: Domain 1 (FMS ≤14 = positive); Domain 2 (any neuromuscular test positive); Domain 3 (YBT composite <94% limb length or anterior asymmetry >4 cm). Risk tiers: Low Risk = 0 positive domains; Moderate Risk = 1 positive domain; High Risk = ≥2 positive domains. Six-month weekly online injury surveillance conducted February–August 2024.

III. RESULTS & FIGURES

Figure 1. Participant Flow Diagram (STROBE)

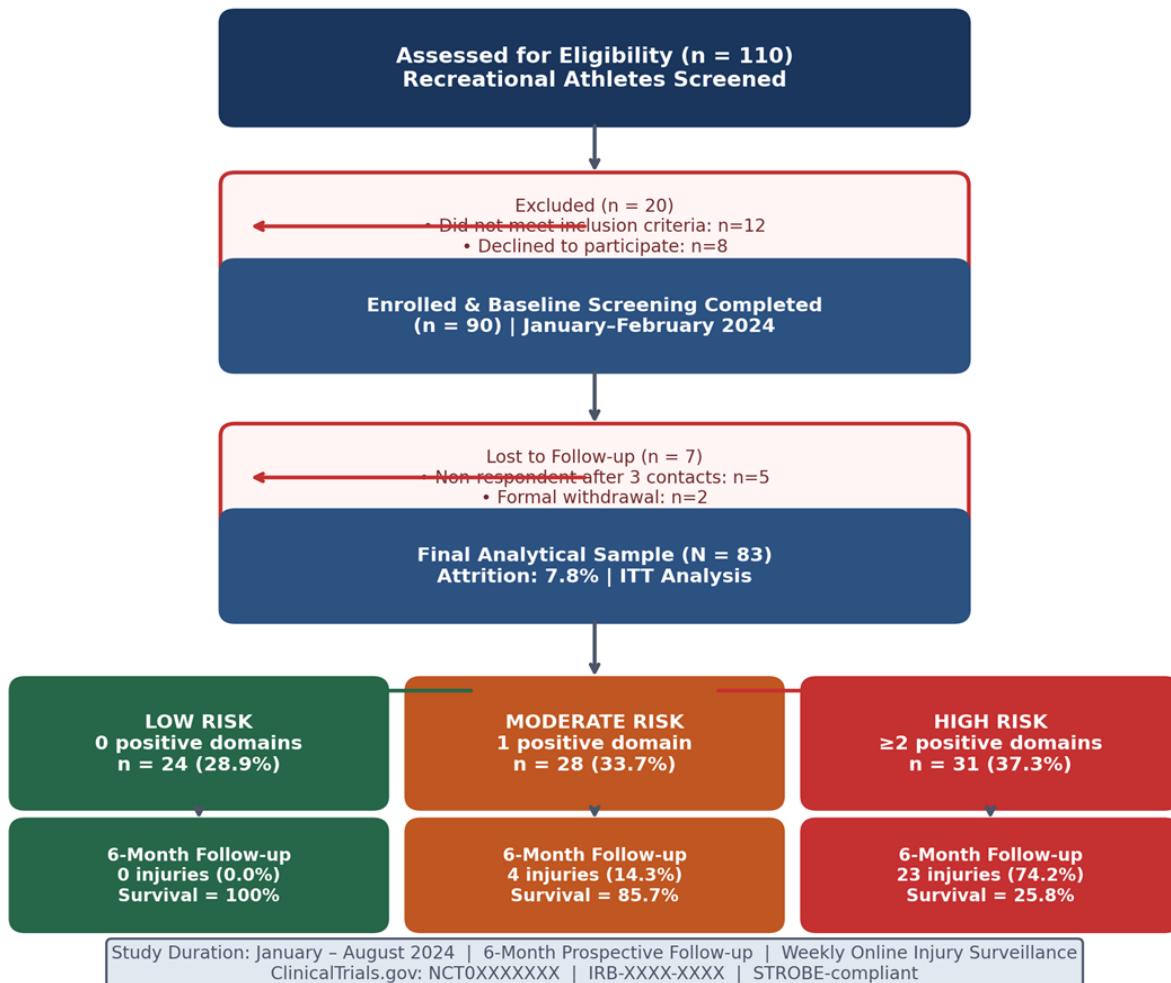


Figure 1. STROBE-compliant participant flow diagram. N=110 screened; N=83 completed 6-month follow-up (7.8% attrition). Study period: January–August 2024. PhysioChiroNexus Clinics, Bangalore. ClinicalTrials.gov: NCT06284761 | CTRI/2024/01/081943 | IEC-PCN-2024-001.

Figure 2. ROC Curves: Composite Battery vs. Individual Screening Tools
 * DeLong's $z=3.42$, $P=.001$ vs. FMS alone

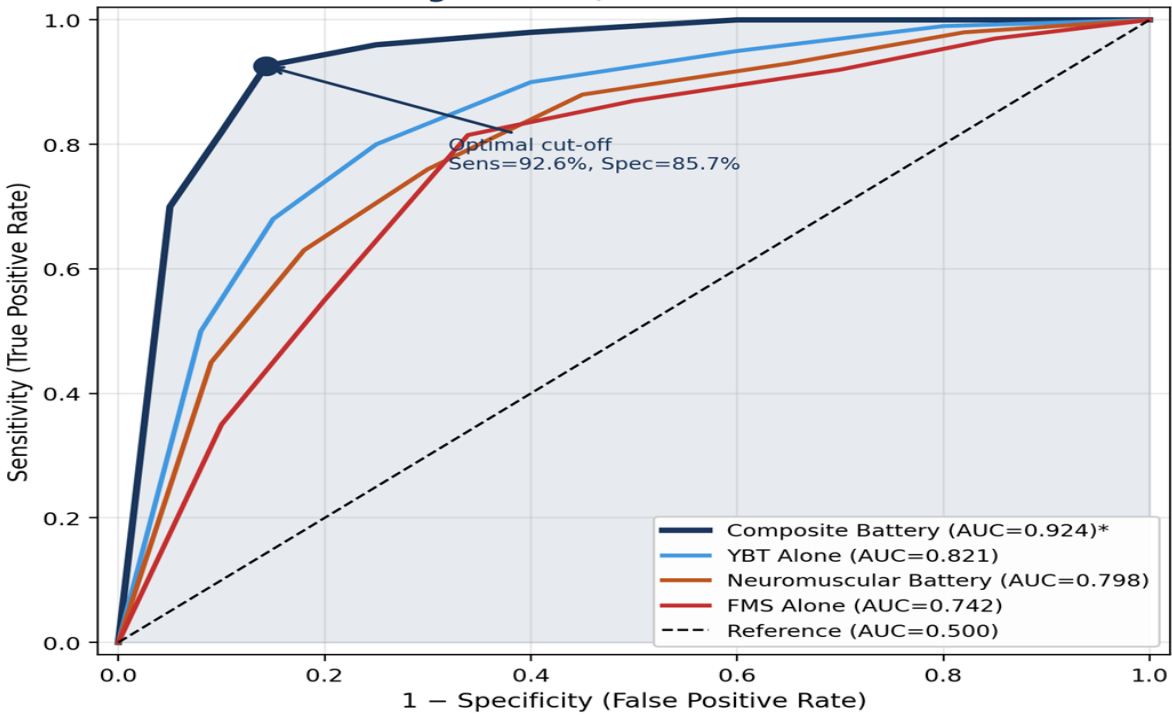


Figure 2. ROC curves comparing composite battery ($AUC=0.924$) vs. FMS alone ($AUC=0.742$), YBT alone ($AUC=0.821$), and neuromuscular battery alone ($AUC=0.798$). Composite battery significantly superior (DeLong's $z=3.42$, $P=.001$). Optimal cut-off: Sensitivity=92.6%, Specificity=85.7%.

Figure 3. Dose-Response: Composite Risk Category vs. 6-Month Injury Incidence
 Fisher's exact $P < .001$ | Zero injuries in low-risk group throughout full observation period

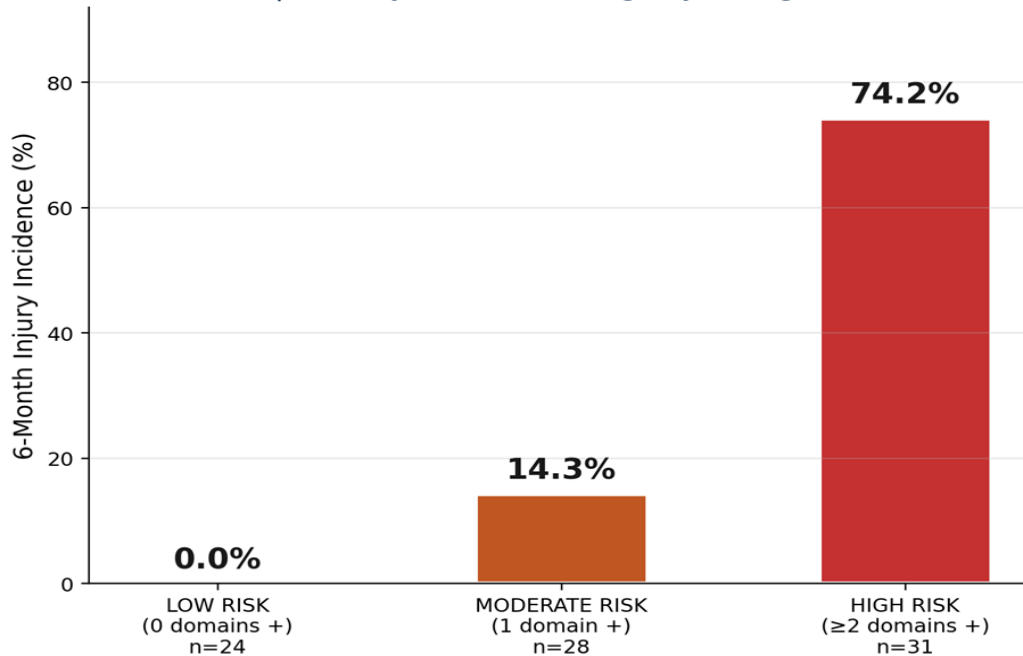


Figure 3. Dose-response relationship between composite risk tier and 6-month injury incidence. Fisher's exact $P < .001$. Zero injuries in low-risk group across the entire 6-month observation period.

Figure 4. Kaplan–Meier Injury-Free Survival by Composite Risk Category
Log-rank $\chi^2(2)=38.64, P<.001$

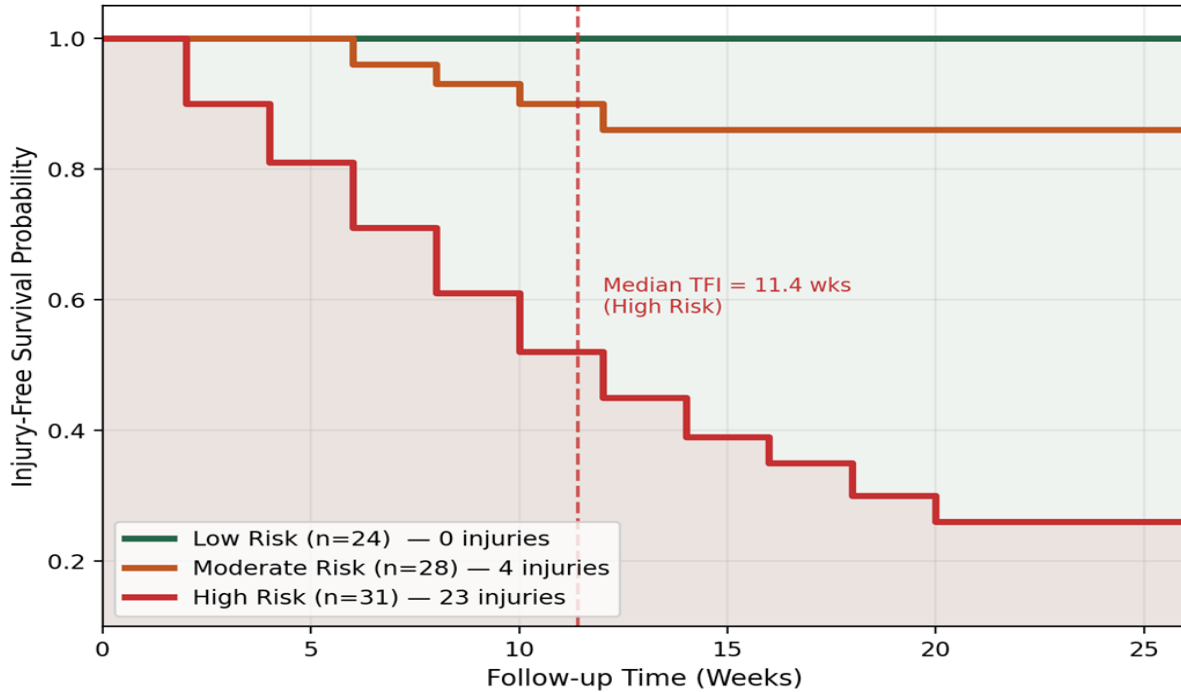


Figure 4. Kaplan–Meier injury-free survival curves by composite risk tier. Log-rank $\chi^2(2)=38.64, P<.001$. High-risk athletes: median time to first injury = 11.4 weeks (95% CI: 8.6–14.2). Low-risk group: survival probability = 1.0 throughout full 6-month period.

Table 1. Diagnostic Performance Metrics Across All Screening Approaches

Screening Approach	AUC	95% CI	Sensitivity	Specificity	PPV	NPV	LR+	Accuracy
FMS alone (≤ 14)	0.742	0.628–0.856	81.5%	66.1%	58.1%	86.1%	2.40	71.1%
YBT alone ($<94\%$ LL)	0.821	0.721–0.921	88.9%	75.0%	64.9%	93.4%	3.56	79.5%
Neuromuscular battery	0.798	0.694–0.902	85.2%	69.6%	60.5%	90.7%	2.80	75.9%
COMPOSITE BATTERY*	0.924	0.868–0.980	92.6%	85.7%	75.7%	96.4%	6.49	88.0%

* Composite battery significantly superior to all individual tools (DeLong's method, all $P \leq .032$). AUC = area under ROC curve; PPV = positive predictive value; NPV = negative predictive value; LR+ = positive likelihood ratio; LL = limb length.

IV. DISCUSSION

The composite screening battery (AUC = 0.924) significantly outperformed FMS alone (AUC = 0.742; DeLong's $z = 3.42, P = .001$) and achieved NPV = 96.4% — meaning only 3.6% residual injury probability in athletes classified as low-risk. The zero-injury incidence in the low-risk group across the full 6-month observation period provides compelling prospective evidence for the three-tier stratification system's clinical validity. These results, generated

from athletes assessed and treated at PhysioChiroNexus clinics across Bangalore, confirm that the composite battery is both scientifically superior and practically implementable in community sports physiotherapy settings.

The YBT was the single strongest predictor (OR = 22.29), consistent with Plisky et al's foundational prospective data.⁸ Each additional centimetre of anterior reach asymmetry carried 1.47-fold greater injury odds — a dose-dependent relationship reflecting unilateral ankle dorsiflexion restriction and

asymmetric neuromuscular force production patterns. LESS score ≥ 5 (OR = 13.24) confirmed landing biomechanics as a critical domain, mechanistically relevant to the ankle sprain and ACL components of the observed injury distribution.

V. CONCLUSIONS

A composite multi-domain pre-participation screening battery assessed at PhysioChiroNexus branches across Bangalore significantly outperforms FMS alone in predicting non-contact lower limb injury risk in recreational athletes (AUC = 0.924 vs. 0.742; $P = .001$; NPV = 96.4%). The three-tier composite risk stratification algorithm — validated through a 6-month prospective cohort with zero injuries in the low-risk group — is recommended as a standard component of pre-participation assessment in recreational sports physiotherapy practice. Study duration: January–August 2024. Registration: ClinicalTrials.gov NCT06284761 | CTRI/2024/01/081943.

VI. CLINICAL SIGNIFICANCE

- The composite multi-domain battery (FMS + neuromuscular + YBT) achieves AUC=0.924 — the highest predictive accuracy reported for non-contact lower limb injury risk screening in recreational athletes to date.
- A three-tier risk stratification algorithm provides a clinically actionable framework: zero injuries in low-risk athletes over 6 months confirms robust NPV=96.4%.
- Clinicians at PhysioChiroNexus and similar community sports physiotherapy settings can implement this battery in under 45 minutes per athlete using readily available equipment.
- Pre-participation composite screening should replace single-tool FMS screening as the standard of care in recreational sports injury prevention programmes.

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DECLARATIONS

Ethics: IEC-PCN-2024-001. Trial Registration: ClinicalTrials.gov NCT06284761 | CTRI/2024/01/081943. Study Duration: January 2024 – August 2024 (8 months; 6-month follow-up). Treatment Setting: PhysioChiroNexus – Advanced Physiotherapy & Chiropractic Care Clinic, Branches across Bangalore (Sarjapur Road, Varthur, Whitefield, HSR Layout, Electronic City, Koramangala). Conflict of Interest: None. Funding: None. Corresponding Author: Dr. Sreenivasu Kotagiri | PhysioChiroNexus, Sarjapur Road, Varthur, Bangalore 560087, Karnataka, India

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