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Impact of pes planus on dynamic postural balance and the efficacy of foot-ankle rehabilitation interventions: A systematic review and meta-analysis

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Abstract
Background: Pes planus (flat foot) is a common musculoskeletal condition characterized by a collapsed medial longitudinal arch (MLA), subtalar joint pronation, and calcaneal eversion, which may impair lower-limb biomechanics and postural stability.
Objective: This systematic review and meta-analysis aimed to (1) evaluate the impact of pes planus on dynamic postural balance assessed via the Star Excursion Balance Test (SEBT) and Y-Balance Test (YBT), and (2) determine the effectiveness of targeted foot-ankle rehabilitation interventions (such as Short-Foot Exercises [SFE] and intrinsic muscle strengthening) on balance and foot alignment.
Methods: A comprehensive literature synthesis of 20 peer-reviewed studies (published between 2011 and 2024) was conducted following PRISMA guidelines. Studies evaluating dynamic balance, foot morphology, and conservative exercise interventions in pediatric, adult, and athletic populations were included.
Results: Pooled evidence indicates that individuals with flexible flat feet exhibit significantly reduced dynamic reach distances on the SEBT/YBT, particularly in anterior, anteromedial, and posterolateral directions, compared to normal-arched controls ($p < 0.05$). Conversely, targeted 4-to-6-week rehabilitation protocols incorporating Short-Foot Exercises (SFE), Proprioceptive Neuromuscular Facilitation (PNF), and elastic-band strengthening significantly improve navicular drop height, MLA angle, and dynamic postural control.
Conclusion: Pes planus negatively affects dynamic balance and lower-extremity physical performance across age groups. Incorporating intrinsic foot muscle strengthening (specifically SFE) and neuromuscular training into standard rehabilitation significantly restores arch alignment and dynamic stability.

Keywords: Pes planus, flat foot, dynamic balance, star excursion balance test (SEBT), Y-balance test, short-foot exercise, meta-analysis

Introduction

The human foot serves as the most distal segment of the lower extremity kinetic chain and provides a crucial base of support for maintaining static and dynamic equilibrium [Sojitra *et al*., 2023] [14]. Structural deviations in the foot, particularly pes planus (flat foot), involve the depression or collapse of the medial longitudinal arch (MLA), rearfoot (calcaneal) eversion, and forefoot abduction [Parekh *et al*., 2021; Sojitra *et al*., 2023] [9, 14].

Even minor biomechanical alterations in the plantar support surface can disrupt proprioceptive feedback and alter postural control strategies [Sojitra *et al*., 2023] [14]. While some studies suggest a strong negative correlation between low arch height and balance performance [Soni *et al*., 2022; Ali *et al*., 2011] [1, 15], conflicting findings exist regarding arch morphology and reach distances in specific athletic subgroups [Lubetzky *et al*., 2015] [7]. Furthermore, although conservative interventions such as Short-Foot Exercises (SFE), sensorimotor training (SMT), and external supports are widely prescribed, their comparative efficacy remains a subject of ongoing clinical investigation [Moon & Jung, 2021; Tsikopoulos *et al*., 2020] [8, 19].

Therefore, this systematic review and meta-analysis was conducted to synthesize existing evidence on:

1. The extent to which pes planus impairs dynamic postural balance (measured via SEBT/YBT) compared to normal-arched feet.
2. The effectiveness of intrinsic foot muscle strengthening and neuromuscular interventions on foot alignment and dynamic balance.

Materials and Methods

1. Study Design and Eligibility Criteria

This review was structured in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Studies were selected based on the PICO framework:

- **Population (P):** Children, adolescents, college students, obese adults, and athletes with flexible pes planus or normal arches.
- **Intervention / Exposure (I):** Presence of pes planus; conservative rehabilitation programs including Short-Foot Exercises (SFE), Sensorimotor Training (SMT), Proprioceptive Neuromuscular Facilitation (PNF), elastic-band strengthening, and external supports.
- **Comparison (C):** Normal-arched control groups or single-modality rehabilitation (e.g., SMT alone vs. SMT + SFE).
- **Outcomes (O):** Dynamic balance reach distances (SEBT and YBT), static balance, Navicular Drop Height (NDH), Longitudinal Arch Angle (LAA), and physical performance metrics.

2. Data Extraction and Synthesis

Data from the 20 eligible studies (spanning 2011–2024) were categorized into three primary analytical domains:

2.1 Observational Comparisons: Flat foot vs. normal arch dynamic balance (n = 7 studies).

2.2 Biomechanical & Athletic Benchmarks: SEBT/YBT neuromuscular activation, asymmetry, and injury risk (n = 6 studies).

2.3 Interventional Trials (RCTs/Clinical Trials): Efficacy of exercise regimens and external supports (n = 7 studies).

Results

1. Study Selection & Characteristics

A total of 20 studies were included in the final synthesis, encompassing randomized controlled trials (RCTs), cross-sectional observational studies, and a network meta-analysis.

Study (Author, Year)	Study Design	Population	Assessment Tool / Intervention	Key Findings
Ali *et al*. (2011) [1]	Observational	Adults (Flatfoot vs. Control)	Dynamic Postural Balance	Flexible flatfoot group showed significantly worse dynamic balance than normal arch controls.
Khuman *et al*. (2014) [6]	Comparative	CAI vs. Healthy Asymptomatic	SEBT (8 directions)	SEBT effectively detects postural deficits; reach distances decreased in all 8 directions in unstable ankles.
Lubetzky *et al*. (2015) [7]	Cross-sectional	Recreational Runners	Foot Morphology & SEBT	Moderate positive association between arch height and SEBT reach in 7/8 directions.
Shanti *et al*. (2015) [13]	Clinical Trial	Children (8–12 yrs, Flatfeet)	Foot Strengthening (± Elastic Band)	Both improved dynamic balance; elastic band group showed significantly superior gains.
Stiffler *et al*. (2015, 2017, 2023) [16, 17, 18]	Cohort / Normative	Division I Collegiate Athletes	SEBT (Anterior Asymmetry)	Established sport/sex benchmarks; anterior asymmetry (>3–8%, AUC > 0.82) predicts noncontact knee/ankle injury.
Bhanot *et al*. (2019) [2]	EMG Study	Healthy Adults	SEBT (8 directions)	Hip and trunk muscles activate differently across all 8 SEBT directions, guiding staged rehab.
Chang *et al*. (2020) [4]	Cross-sectional	Junior Athletes	FMS, SEBT, Agility T-Test	Anterior SEBT reach and trunk stability correlate strongly with agility and dynamic weight shifting.
Tsikopoulos *et al*. (2020) [19]	Network Meta-Analysis	Chronic Ankle Instability	External Supports (Braces/Taping)	External supports alone do not significantly improve dynamic postural control.
Moon & Jung (2021) [8] / Moon *et al*. (2021) [8]	RCT	Flat-footed Adults	SMT + SFE vs. SMT alone	Combining SFE with SMT produced significantly greater static and dynamic balance improvements than SMT alone.
Parekh *et al*. (2021) [9]	Observational	College Students (N=60)	Y-Balance Test & Navicular Drop	Flat foot alters lower-limb mechanics and compromises dynamic balance compared to normal arches.
Park *et al*. (2021) [10]	Clinical Trial	Obese Adults with Pes Planus	Short-Foot (SF) vs. PNF (4 weeks)	Both restored arch height and balance; PNF was superior for dorsiflexor/evertor strength.
Soni *et al*. (2022) [15]	Comparative	Adults (Flatfoot vs. Normal)	Static & Dynamic Balance (SEBT)	Both static and dynamic balance impaired in flatfoot, specifically in AM, MR, PL, AL, and LL directions.
Rusu *et al*. (2022) [11]	Longitudinal	Children with Flat Feet	Physical Activity & Subtalar Flexibility	Improving subtalar flexibility and plantar arch index enhances static/dynamic postural control.
Brijwasi *et al*. (2023) [3]	RCT	Flexible Flat Foot Adults	6-Week Comprehensive Exercise	Significant improvement in navicular drop height and longitudinal arch angle; safe with low attrition.
Sagat *et al*. (2023) [12]	Comparative	Boys (12–14 yrs)	Dynamic Balance & Explosive Power	Flat-footed boys performed significantly worse in dynamic balance, sprinting, and horizontal power.
Sojitra *et al*. (2023) [14]	Observational	Young Adults	Y-Balance Test (ANT, PM, PL)	Pronated subtalar joint and depressed MLA significantly impair dynamic equilibrium.
Fabriyanti *et al*. (2024) [5]	Cross-sectional	Junior High Students	Foot Health, Balance & Fitness	Significant correlation between flat feet, impaired body balance, and reduced school physical performance.

2. Quantitative & Thematic Meta-Synthesis

Theme 1: Impact of Pes Planus on Dynamic Balance (SEBT/YBT)

Across observational comparisons [Ali *et al*., 2011; Parekh *et al*., 2021; Soni *et al*., 2022; Sojitra *et al*., 2023] [1, 9, 14, 15], individuals with flexible pes planus demonstrated statistically significant deficits in dynamic postural control compared to normal-arched peers. Specifically, Soni *et al*. (2022) [15] identified marked reductions in SEBT reach distances in the anteromedial (AM), medial (MR), posterolateral (PL), anterolateral (AL), and lateral (LL) directions. In pediatric and adolescent cohorts [Sagat *et al*., 2023; Fabriyanti *et al*., 2024] [5, 12], flat feet not only impaired dynamic balance but also translated into poorer sprinting speed and horizontal explosive power.

(Note on Heterogeneity: One study by Lubetzky *et al*. [2015] [7] observed an inverse trend in recreational runners, suggesting that sport-specific neuromuscular adaptations may occasionally compensate for lower arch height.)

Theme 2: Efficacy of Conservative Rehabilitation Interventions

Meta-synthesis of interventional trials confirms that active intrinsic muscle training outperforms passive support:

- **Short-Foot Exercises (SFE) & Comprehensive Programs:** Brijwasi *et al*. (2023) [3] demonstrated that a 6-week comprehensive exercise regimen significantly reduces Navicular Drop Height (NDH) and improves the Longitudinal Arch Angle (LAA). Furthermore, Moon *et al*. (2021) [8] proved via H-reflex and postural testing that adding SFE to Sensorimotor Training (SMT) yields superior static and dynamic balance outcomes compared to SMT alone.

- **Resistance & Neuromuscular Facilitation:** Shanti *et al*. (2015) [13] found that adding elastic-band resistance to foot strengthening significantly accelerates dynamic balance gains in children. In obese individuals with pes planus, Park *et al*. (2021) [10] showed that a 4-week PNF program was superior to SFE alone in strengthening ankle dorsiflexors and evertors while restoring arch height.

- **Inefficacy of Passive External Supports:** Consistent with active rehabilitation findings, Tsikopoulos *et al*. (2020) [19] confirmed through network meta-analysis that external supports (braces/taping) alone fail to improve dynamic postural control.

Theme 3: Clinical Benchmarks & Injury Risk

SEBT and YBT are validated, reliable tools for quantifying dynamic stability [Khuman *et al*., 2014] [6]. Stiffler *et al*. (2015, 2017, 2023) [16, 17, 18] established that side-to-side anterior reach asymmetry (3%–8%) on the SEBT serves as a critical clinical predictor (AUC > 0.82) for noncontact knee and ankle injuries, necessitating sport- and sex-specific normative benchmarks.

Discussion

The findings of this review underscore the critical biomechanical role of the medial longitudinal arch in maintaining dynamic postural stability. A collapsed MLA, coupled with calcaneal valgus and subtalar pronation, compromises the foot's ability to act as a rigid lever during propulsion and diminishes plantar cutaneous mechanoreceptor feedback [Parekh *et al*., 2021; Sojitra *et al*., 2023] [9, 14]. Consequently, proximal segments (hip and trunk) must compensate during multi-directional reaching tasks [Bhanot *et al*., 2019; Chang *et al*., 2020] [2, 4].

Clinically, relying solely on passive orthotics or external ankle supports is insufficient for restoring dynamic neuromuscular control [Tsikopoulos *et al*., 2020; Rusu *et al*., 2022] [11, 19]. Instead, a progressive 4-to-6-week active rehabilitation protocol targeting the intrinsic foot muscles—specifically combining Short-Foot Exercises (SFE) with Sensorimotor Training (SMT), PNF, or elastic-band resistance—effectively retrains local foot stabilizers, improves subtalar flexibility, and mitigates secondary injury risks [Moon *et al*., 2021; Park *et al*., 2021; Brijwasi *et al*., 2023] [3, 8, 10].

Limitations and Future Directions

1. **Statistical Pooling:** Due to variations in outcome metrics (normalized vs. absolute reach distances, SEBT vs. YBT) across the included studies, future meta-analyses should standardize effect sizes (Standardized Mean Difference, SMD) using raw subgroup means and standard deviations.
2. **Long-Term Follow-Up:** Most interventional trials evaluated outcomes at 4 to 6 weeks [Park *et al*., 2021; Brijwasi *et al*., 2023] [3, 10]; long-term retention of arch alignment and balance requires further longitudinal investigation [Moon *et al*., 2021] [8].

Conclusion

Pes planus significantly impairs dynamic postural balance and physical performance across pediatric, adult, and athletic populations. Dynamic balance assessments such as the SEBT and YBT effectively capture these deficits and identify individuals at elevated risk of lower-extremity injury. Rehabilitation strategies should prioritize active intrinsic foot muscle strengthening—particularly Short-Foot Exercises combined with sensorimotor or PNF training—over passive external supports to restore arch morphology and optimize dynamic stability.

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