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BODY MASS INDEX AND INTRINSIC FOOT MUSCLE STRENGTH AS DETERMINANTS OF FLEXIBLE FLAT FOOT IN DIABETES

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Abstract

Background: *Flexible flatfoot is a common musculoskeletal alteration in people with diabetes. Increased body mass index (BMI) and weakness of intrinsic foot muscles may contribute to medial longitudinal arch collapse. However, limited evidence exists on their association with flexible flatfoot in diabetic populations. The purpose of this study was to determine the association of flexible flatfoot with BMI and intrinsic foot muscle strength in patients with diabetes.*

Methods: *A cross-sectional study was conducted among 286 diabetic patients aged 35–55 years recruited from tertiary care hospitals in Peshawar. Participants with neuropathy or neuromuscular disorders were excluded. BMI was categorized using Asian cut-offs. The navicular drop test (≥10 mm) was used to assess flexible flatfoot. The intrinsic muscles of the foot; Tibialis posterior and abductor hallucis muscle strength was measured using manual muscle testing. Data were analyzed with chi-square tests in SPSS v.27, with significance value set at $p < 0.05$.*

Results: *The mean age of participants was 48.4 ± 6.4 years; 46.2% were male & females 53.8%. Based on BMI, 44.1% were normal weight and 55.9% overweight; underweight and obese patients were excluded. Flexible flatfoot was observed in 52.4% of participants. Muscle strength grading showed 29.4% of tibialis posterior and 40.6% of abductor hallucis at grade 3 strength. Chi-square analysis demonstrated significant associations of flexible flatfoot with BMI ($p < 0.001$), tibialis posterior strength ($p < 0.001$), and abductor hallucis strength ($p < 0.001$).*

Conclusion: *Flexible flatfoot is highly prevalent among diabetic patients and is significantly associated with higher BMI and reduced intrinsic foot muscle strength.*

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Introduction

Flexible flatfoot, or flexible pes planus, is a dynamic foot deformity characterized by collapse of the medial longitudinal arch on weight bearing with restoration of the arch when non-weight bearing. It is distinguished by the talus's medial rotation and plantar flexion, the calcaneus's eversion, the collapsed medial arch, and the forefoot's abduction(1). The condition involves complex changes in foot alignment including hindfoot eversion, forefoot abduction, and midfoot pronation, and results from a combination of passive (ligamentous and plantar aponeurosis) and active (muscle) support failures(2). Furthermore, experts in the field of foot and ankle disorders concur that flatfoot is one of the most common pathologies seen in adults. There is a negative correlation between foot diseases and their symptoms and poor health outcomes, including falls and functional restrictions)(3). In people with diabetes mellitus, changes in foot structure and function are clinically important because they may compound the already elevated risk of foot complications. Degenerative processes associated with high glucose levels and impaired blood circulation cause weak tibial tendon and altered senses in diabetics(4). Studies comparing diabetic and non-diabetic populations have reported higher prevalence of structural foot alterations in diabetes, including flatter arches and skin/dermal changes that may predispose to pressure redistribution and ulceration(5, 6).

Elevated body mass index (BMI) increases mechanical loading across the medial longitudinal arch and plantar tissues, which can accelerate arch collapse and lead to symptomatic or structural flatfoot over time(7). The relationship between obesity/BMI and flatfoot has been reported across age groups and settings, with higher BMI associated with flatter feet or greater pronation(8, 9). In diabetic populations, where overweight and obesity are common, the mechanical burden of increased BMI may be especially relevant to arch integrity and foot health(1). Active muscular support from intrinsic foot muscles (e.g., abductor hallucis) and key extrinsic muscles (notably tibialis posterior) plays a central role in dynamic arch maintenance. The tibialis posterior provides important inversion and arch-supporting force; its dysfunction is a well-recognized cause of adult acquired flatfoot or progressive collapsing foot deformity. Intrinsic muscles (such as the abductor hallucis) contribute to short-term arch stabilization during stance and single-leg tasks, and weakness of these muscles has been linked to increased navicular drop and pronation in several studies(10, 11)

The existence of other illnesses, age, and the type of population under study all affect prevalence. Intervention studies and trials demonstrate that targeted exercises (short-foot exercises, abductor hallucis strengthening, and combined programs) can reduce navicular drop and improve foot function, supporting the clinical relevance of muscle strength to arch mechanics (12, 13). Recent systematic reviews and randomized trials have shown beneficial effects of exercise and orthoses on symptomatic flatfoot, though effects on static navicular height can be variable depending on duration and population (14, 15). Despite this mechanistic and interventional evidence, there is a relative paucity of focused research examining the joint contribution of BMI and intrinsic/extrinsic foot muscle strength to flexible flatfoot specifically in people with diabetes. Some studies in diabetic cohorts have described higher rates of midfoot deformity and associations with posterior tibial dysfunction, but many include patients with peripheral neuropathy or mixed samples, making it difficult to isolate the role of muscle strength and BMI in neuropathy-free diabetic populations(16, 17). Given the high burden of weight-related comorbidity in diabetes and the potential for targeted rehabilitation (weight management, muscle strengthening) to mitigate foot deformity and downstream complications, there is a clear rationale for studies that assess BMI and foot muscle strength as determinants of flexible flatfoot in neuropathy-free diabetic patients. Filling this gap can guide screening priorities (who to examine for flatfoot), inform rehabilitation targets (which muscles to strengthen), and help tailor preventive strategies to reduce plantar pressure redistribution and risk of tissue breakdown in diabetes.

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Accordingly, the present cross-sectional study used the navicular drop test (≥10 mm threshold) to identify flexible flatfoot and standardized manual muscle testing for tibialis posterior and abductor hallucis to evaluate muscle strength. The study excluded patients with neuropathy or neuromuscular disorders to reduce confounding by neuropathic muscle impairment. Using Asian BMI cutoffs, the study investigates whether higher BMI and reduced intrinsic/extrinsic foot muscle strength are associated with a higher prevalence of flexible flatfoot among patients with diabetes. The findings aim to provide clinically actionable evidence relevant to diabetic foot screening and rehabilitation planning.

Material and Methods

Study design and setting

An analytical cross-sectional study was conducted between June 2024 - December 2025 in two tertiary care hospitals in Peshawar, Pakistan: Lady Reading Hospital and Hayatabad Medical Complex. The study was designed to evaluate the association of flexible flatfoot with BMI and intrinsic foot muscle strength among patients with diabetes. The ethical approval was obtained from the IRB, Northwest Institute of Health Sciences, Peshawar with the *Ref. #: 06/12/47/NWIHS-DPT/IRB/2024.*

Participants Eligibility Criteria

A total of 286 patients with medically diagnosed diabetes, both Male/Female aged 35–55 years, were included in the study and recruited using a convenience sampling method into the study. Patients with medically diagnosed rheumatoid arthritis, secondary edema, congenital lower limb anomalies, peripheral neuropathy, neuromuscular disorders, recent history of trauma, injury or surgery of lower limb, pregnant women, underweight (BMI<18.5 kg/ m^2) and obese patients (BMI ≥30 kg/m^2) were excluded from the study to reduce confounding effects. Individuals with musculoskeletal deformities other than flatfoot were also excluded. Written informed consent was obtained from all participants before enrollment.

Anthropometric measurements

Body weight was measured to the nearest 0.1 kg using a calibrated digital scale, and height was recorded to the nearest 0.1 cm using a stadiometer. BMI was calculated as weight (kg)/height (m^2). Classification was based on Asian-specific BMI cutoffs: underweight (<18.5 kg/m^2), normal weight (18.5–22.9 kg/m^2), overweight (23.0–27.4 kg/m^2), and obese (≥27.5 kg/m^2)(18). The two extremes of BMI; Underweight & Obese patients, were excluded; therefore, only normal weight and overweight participants were included in the analysis.

Assessment of flexible flatfoot

Flexible flatfoot was assessed using the navicular drop test (Fig. 1). Participants were seated with feet flat on the floor, and the height of the navicular tuberosity from the floor was measured in subtalar neutral position. The participant was then asked to stand in a relaxed position, and the navicular height was re-measured. A difference of ≥*10 mm* between seated and standing measurements was considered positive for flexible flatfoot, consistent with previous studies(19).

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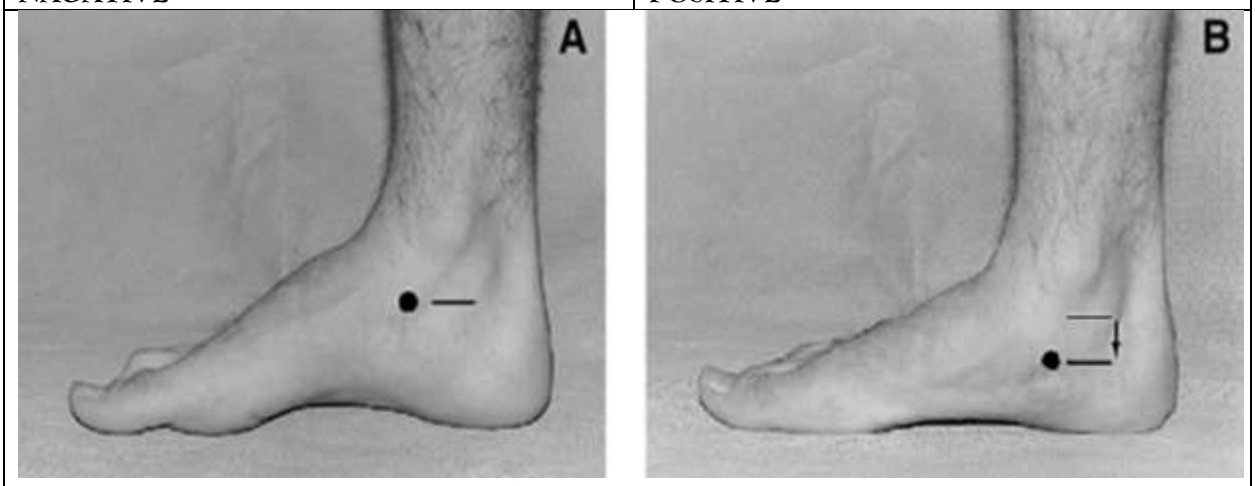

Figure 1 Navicular Drop Test (Positive vs Negative)

Muscle strength assessment

Strength of the tibialis posterior and abductor hallucis muscles was evaluated using Manual Muscle Testing (MMT), following standardized grading procedures. Strength was scored on a 0–5 scale, with grade 3 indicating movement against gravity, grade 4 indicating movement against moderate resistance, and grade 5 representing normal strength against full resistance (Fig. 2). Muscle grading was performed by trained physiotherapists to minimize inter-rater variability.

Grade	Description	Criteria
0	No contraction	No contraction can be felt in the muscle
1	Trace muscle contraction	Muscle contraction can be felt on palpation but without motion
2	Poor muscle contraction	Muscle contraction and motion of the segment in a gravity discarded position (gravity minimized)
3	Muscle contraction	Full motion of the segment against gravity
4	Good muscle contraction	Full motion of the segment against gravity and moderate resistance
5	Normal muscle contraction	Full motion of the segment against gravity and maximal resistance

Figure 2 Manual Muscle Testing Gradings

Data analysis

Data were analyzed using SPSS version 27. Descriptive statistics (mean, standard deviation, frequencies, percentages) were calculated for demographic and clinical characteristics. Chi-square tests were used to examine associations between flexible flatfoot and categorical variables (BMI categories, tibialis posterior strength, abductor hallucis strength). A p-value of <0.05 was considered statistically significant.

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Results

Participants Demographics

A total of 286 patients with diabetes were enrolled. The mean age was 48.4 ± 6.4 years (range: 35–55). Of these, 132 (46.2%) were male and 154 (53.8%) were female (Fig.3). Using Asian BMI cutoffs, 126 (44.1%) were classified as normal weight and 160 (55.9%) as overweight (Fig 4). Patients with obesity (BMI ≥27.5 kg/m²) were excluded. The demographic and descriptive statistics are present in Table 1).

Table 1 Demographic and anthropometric characteristics of participants (n=286)

Variable	Category	N	Mean ± S.D / %
Age (in years)		286	48.44 ± 6.39
Anthropometric Measurement	Weight (in KGs)	286	78.05 ± 10.26
	Height (in Meters)	286	1.67 ± 0.11
Gender	Male	179	62.6%
	Female	107	37.4%
Body Mass Index (BMI)	<18.5 (Under Weight)	0	0%
	18.5-24.9 (Healthy Weight)	126	44.1%
	25.0 – 29.9 (Overweight)	160	55.9%
	30.0 and Above (Obese)	0	0%

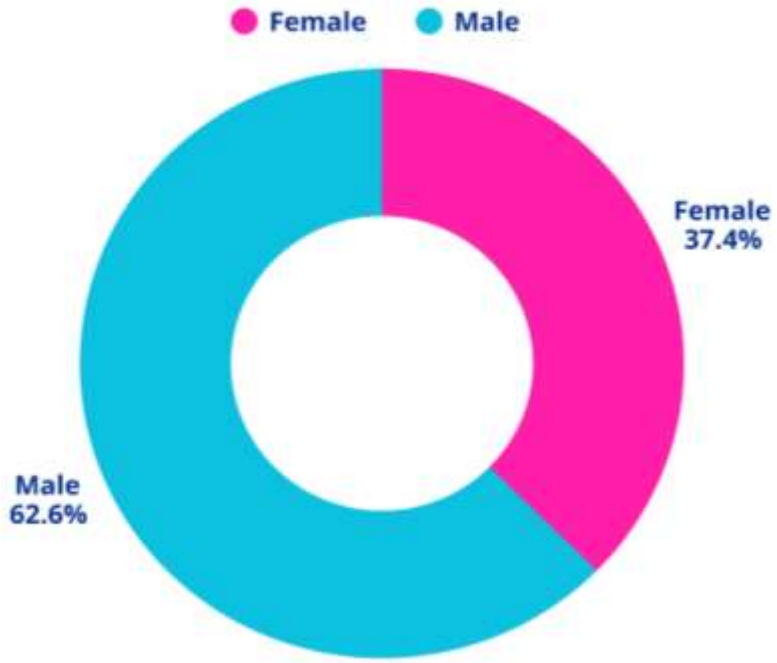

Figure 3 Gender Distribution in the study participants

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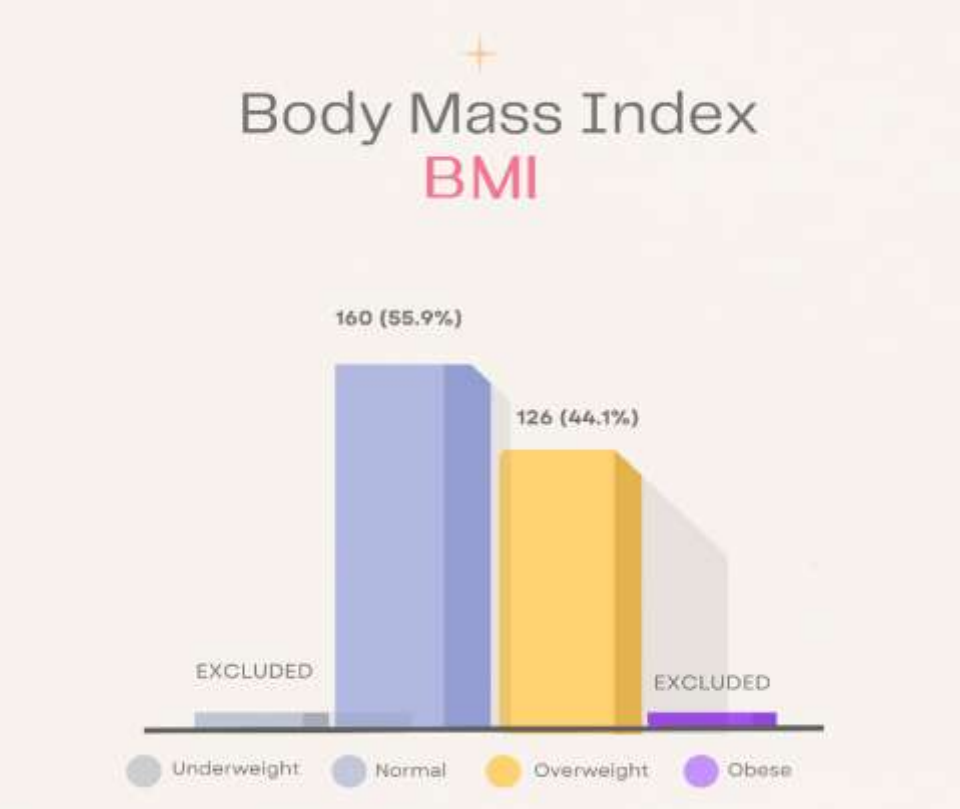

Figure 4 Distribution of participants across BMI categories (normal weight vs overweight) (Asian cutoffs)

Prevalence of flexible flatfoot and BMI

In total of 126 patient with normal BMI, 40.0% reported Flatfoot, while 62.5% of the Flatfoot patients were overweight BMI category (Table 2, Fig. 5).

Table 2 Prevalence of flexible flatfoot and BMI

BMI Category	Flatfoot Present (n)	Flatfoot Absent (n)	Flatfoot Prevalence (%)
Normal weight (n=126)	50	76	40.0%
Overweight (n=160)	100	60	62.5%
Total (n = 286)	150	136	

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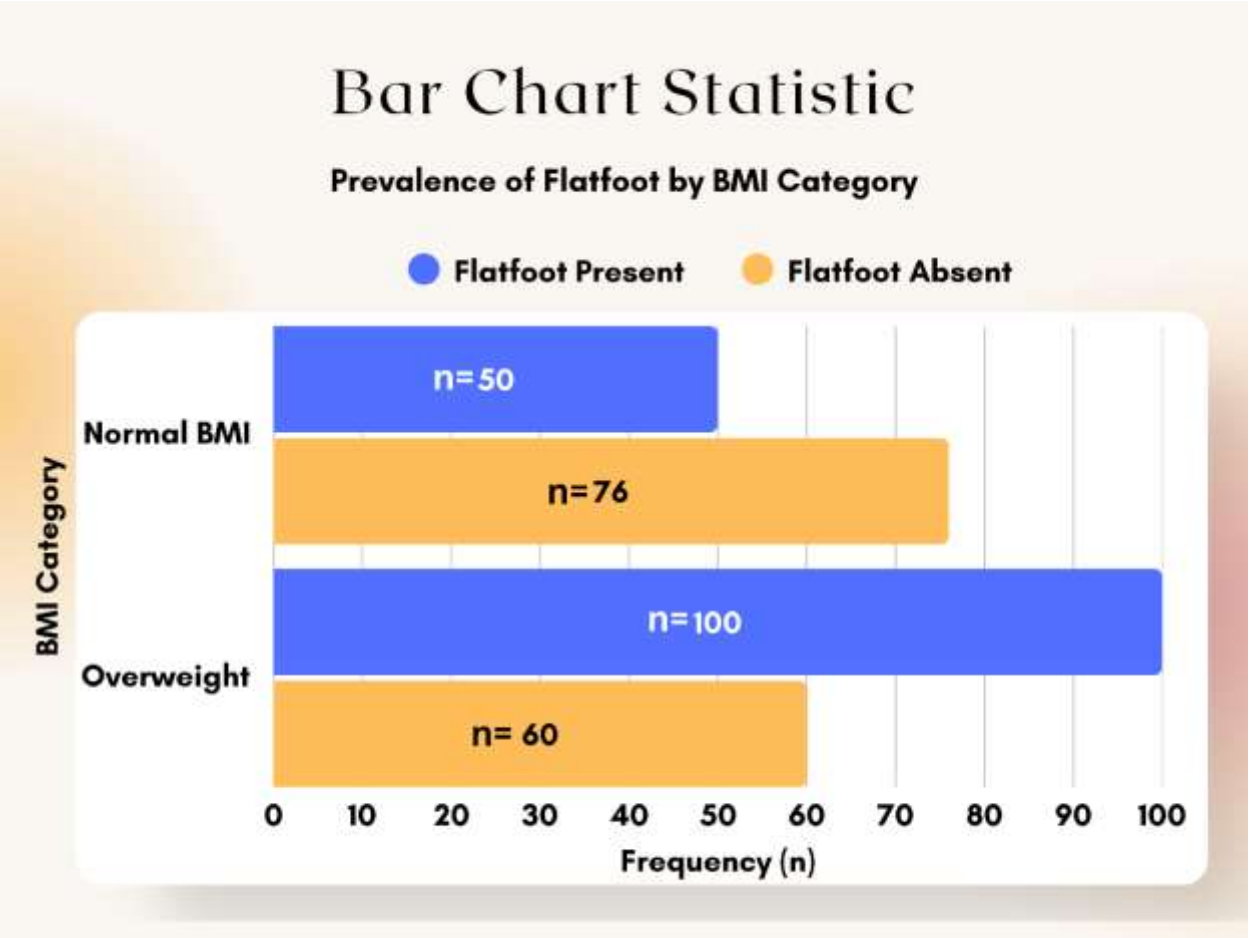

Figure 5 Prevalence of flexible flatfoot stratified by BMI category

Flexible Flatfoot and muscle strength distribution

Flexible flatfoot, defined as navicular drop ≥10 mm, was present in 150 participants (52.4%) and absent in 136 (47.6%). For tibialis posterior muscle strength, 84 (29.4%) participants were graded at 3, 70 (24.5%) at grade 4, and 132 (46.2%) at grade 5. For abductor hallucis muscle strength, 116 (40.6%) were graded at 3, 38 (13.3%) at grade 4, and 132 (46.2%) at grade 5 (Table 3).

Table 3 Flexible flatfoot and muscle strength distribution by MMT Grading

Variable	Grade/Status	Frequency (n)	Percentage %
Navicular Drop Test	Positive	150	52.4%
	Negative	136	47.6%
Tibialis Posterior - MMT Grading	G-0 - No Contraction	0	0%
	G-1 - Trace muscle contraction	0	0%
	G-2 - Poor muscle contraction	0	0%
	G-3 - Muscle Contraction	84	29.4%
	G-4 - Good muscle contraction	70	24.5%
	G-5 - Normal muscle contraction	132	46.2%

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Abductor Hallucis Longus - MMT Grading	G-0 - No Contraction	0	0%
	G-1 - Trace muscle contraction	0	0%
	G-2 - Poor muscle contraction	0	0%
	G-3 - Muscle Contraction	116	40.6%
	G-4 - Good muscle contraction	38	13.3%
	G-5 - Normal muscle contraction	132	46.2%

Association of flexible flatfoot with BMI and muscle strength

Chi-square analysis revealed significant associations between flexible flatfoot and BMI category ($p < 0.001$). Similarly, flexible flatfoot was significantly associated with tibialis posterior strength ($p < 0.001$) and abductor hallucis strength ($p < 0.001$) (Detailed analysis is presented in Table 4).

Table 4 Association of flexible flatfoot with BMI and muscle strength

Association	Category	Status	Frequency (%)	χ^2 (df, N)	p-value
Flexible flatfoot vs BMI	Underweight (<18.5)	Positive	0 (0%)	χ^2 (1, N=286) = 25.617	<0.001
		Negative	0 (0%)		
	Healthy Weight (18.5-24.9)	Positive	5 (1.7%)		
		Negative	121 (42.3%)		
	Overweight (25.0 – 29.9	Positive	145 (50.7%)		
		Negative	15 (5.2%)		
Flexible flatfoot vs Tibialis posterior strength	Grade 1	Positive	0 (0%)	χ^2 (2, N=286) = 54.203	<0.001
		Negative	0 (0%)		
	Grade 2	Positive	0 (0%)		
		Negative	0 (0%)		
	Grade 3	Positive	83 (29.0%)		
		Negative	1 (0.3%)		
	Grade 4	Positive	67 (23.4%)		
		Negative	3 (1%)		
	Grade 5	Positive	0 (0%)		
		Negative	150 (52.4%)		
Flexible flatfoot vs Abductor hallucis strength	Grade 1	Positive	0 (0%)	χ^2 (2, N=286) = 30.185	<0.001
		Negative	0 (0%)		
	Grade 2	Positive	0 (0%)		
		Negative	0 (0%)		
	Grade 3	Positive	115 (40.2%)		
		Negative	1 (0.3%)		
	Grade 4	Positive	35 (12.2%)		
		Negative	3 (1%)		
	Grade 5	Positive	0 (0%)		
		Negative	132 (46.2%)		

Discussion

This study investigated the association of flexible flatfoot with BMI and intrinsic foot muscle strength in patients with diabetes. The results demonstrate a high prevalence of flexible flatfoot (52.4%) in this population, and significant associations were observed between flexible flatfoot and higher BMI, as well as with reduced strength of the tibialis posterior and abductor hallucis muscles.

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The prevalence of flexible flatfoot in this study is consistent with previous findings that have reported high rates of foot deformities among patients with diabetes. Structural changes in the medial longitudinal arch have been linked to obesity, altered plantar pressures, and impaired muscle control(1, 4). In our study, more than half of the participants exhibited navicular drop ≥10 mm, reinforcing the importance of routine screening for flatfoot in diabetic populations. The significant association between BMI and flexible flatfoot aligns with existing literature showing that higher BMI increases mechanical loading on the arch and accelerates arch collapse [3,4]. Several studies in both diabetic and non-diabetic populations have shown that overweight and obesity are predictors of flatfoot and related deformities. For example, Ubillus et al. (9)reported that obesity was strongly associated with foot and ankle pathology, while Auricchio et al. (8) demonstrated a positive correlation between BMI and flatfoot posture in adults. Given the high prevalence of overweight in diabetic populations, these findings underscore the role of weight management in reducing the risk of arch collapse and secondary complications.

Intrinsic and extrinsic foot muscles provide dynamic stability to the medial arch. In particular, the tibialis posterior is recognized as the primary dynamic stabilizer of the arch, and dysfunction in this muscle is a major cause of adult acquired flatfoot(10). The abductor hallucis, as one of the key intrinsic muscles, contributes to maintaining medial arch height during weight-bearing tasks(11). Our findings of significant associations between reduced muscle strength and flexible flatfoot support prior evidence that weakness of these muscles contributes to medial arch collapse. Namsawang et al. (12) and Goo et al. (13) both demonstrated that strengthening programs targeting the abductor hallucis and related muscles improved foot posture and reduced navicular drop in individuals with flatfoot. These results highlight the potential of incorporating intrinsic and extrinsic muscle training into rehabilitation programs for diabetic patients. From a clinical perspective, the findings have important implications. Flexible flatfoot in diabetic patients may predispose to abnormal plantar pressure distribution, balance impairment, gait dysfunction, and increased risk of ulceration, particularly when combined with neuropathy or vascular compromise(16, 20). Although patients with neuropathy were excluded in this study, addressing modifiable factors such as BMI and muscle strength could reduce the risk of progression to irreversible deformities and related complications. Interventions such as structured weight management, intrinsic foot muscle strengthening, and use of supportive orthoses may help to preserve foot structure and function in this population.

The study also contributes to addressing a gap in the literature. While many studies have described the prevalence of flatfoot in general populations, few have specifically examined its determinants in diabetic patients without neuropathy. By focusing on BMI and muscle weakness, this study provides novel insights into potentially modifiable risk factors in this high-risk group.

Strengths and limitations

A major strength of this study is the use of standardized assessment methods: navicular drop test with a validated ≥10 mm threshold and manual muscle testing of both tibialis posterior and abductor hallucis. Exclusion of neuropathic patients minimized confounding by nerve-related muscle impairment. However, limitations should be acknowledged. The cross-sectional design precludes causal inference. The use of convenience sampling limits generalizability beyond the studied population. Data on type of diabetes, duration of disease, glycemic control (HbA1c), and comorbidities such as hypertension or peripheral arterial disease were not available, though these factors could influence foot structure and function. Manual muscle testing, while practical, is less precise than objective dynamometry. Finally, obesity was excluded, which may underestimate the true prevalence of flatfoot in the wider diabetic population.

Conclusion

Flexible flatfoot was found in over half of the diabetic patients included in this study and

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showed significant associations with higher body mass index and reduced intrinsic and extrinsic foot muscle strength. These findings highlight BMI and muscle weakness as important determinants of medial arch collapse in this population. Routine screening and early recognition of flatfoot should be considered in diabetic care, with particular attention to patients who are overweight or who demonstrate reduced foot muscle strength.

Clinical Implications

The findings emphasize the importance of early screening for flatfoot in diabetic patients, particularly those with higher BMI and weaker intrinsic foot muscles. Incorporating arch assessment into routine diabetic foot evaluations may help identify patients at risk. Rehabilitation programs focusing on intrinsic and extrinsic foot muscle strengthening, combined with weight control interventions, may reduce the burden of foot deformity and its complications. Some of the implications are describe below in detail separately.

- **Early screening:** Incorporating navicular drop testing into routine diabetic foot assessments may help identify patients at risk of flexible flatfoot before structural deformities become fixed.
- **Targeted interventions:** Structured programs emphasizing weight management and strengthening of tibialis posterior and abductor hallucis can improve dynamic arch support and potentially reduce the prevalence of flatfoot-related complications.
- **Preventive care:** Early interventions may help reduce abnormal plantar pressure distribution, balance impairment, and ulceration risk, contributing to better overall foot health in diabetic patients.

Recommendations

1. **Routine assessment:** Incorporate BMI evaluation and foot muscle strength testing into standard diabetic foot screening protocols.
2. **Rehabilitation strategies:** Physiotherapy programs focusing on intrinsic and extrinsic foot muscle strengthening should be implemented for patients with early signs of flatfoot.
3. **Weight management:** Lifestyle modification and weight reduction interventions should be prioritized for overweight diabetic patients to reduce the mechanical burden on the medial longitudinal arch.
4. **Longitudinal studies:** Future research should adopt longitudinal designs to establish causal relationships and assess the impact of strengthening and weight management interventions on the progression of flatfoot in diabetic populations.
5. **Broader risk assessment:** Studies should include data on diabetes duration, glycemic control (HbA1c), and comorbidities such as neuropathy or vascular disease to more fully understand risk factors for foot deformities.

6. CRediT authorship contribution statement:

CRediT	Author's Contribution
Conceptualization	1,2,3,4,5,6,7,8,9
Methodology	1,2,3,7
Data curation	1,2,5,7
Writing - original draft	1,6,8,9
Writing - review & editing	8,9

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Ethical Approval: The ethical approval was obtained from the IRB, Northwest Institute of Health Sciences, Peshawar with the *Ref. #: 06/12/47/NWIHS-DPT/IRB/2024.*

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Conflicts of Interest

The authors declare no conflicts of interest related to this study.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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