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ORIGINAL ARTICLE

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The effect of different designs of custom foot orthoses on pain and balance in individuals with plantar fasciitis: A randomized controlled trial with 6-month follow-up

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Abstract

Background: Plantar fasciitis (PF) is a common cause of heel pain that significantly affects daily activities. Although custom foot orthoses (CFOs) are widely used to treat this condition, there is limited evidence comparing different orthotic designs and their effects on balance parameters.

Objective: To investigate the effects of different types of CFOs on pain and static and dynamic balance in individuals with PF.

Design: Randomized controlled trial.

Patients: 120 participants with PF (age 44.3 ± 10.1 years; 72.5% female; body mass index 26.5 ± 4.9 kg/m^2).

Interventions: All participants were randomly allocated to receive either CFOs without wedge (control group), CFOs with orthotic wedge type 1 (W1), or CFOs with orthotic wedge type 2 (W2), all of which were prescribed for daily weight-bearing activities.

Main Outcome Measures: Pain intensity, dynamic balance from the Y Balance Test, and static balance were assessed at baseline, 3-month, and 6-month follow-up. Static balance parameters were measured using a force platform under four conditions: eyes closed on firm surface (ECFS), eyes closed on soft surface (ECSS), eyes open on firm surface (EOFS), and eyes open on soft surface (EOSS).

Results: All three interventions significantly reduced pain and improved dynamic balance over the 6-month period ($p < .01$). The CFO group showed significantly better static balance in center of mass sway during ECFS ($p < .01$), ECSS (95% confidence ellipse area; $p = .042$), and EOSS ($p < .05$) compared to both the W1 and W2 groups.

Conclusion: Although all three interventions effectively reduced pain and improved dynamic balance. The CFOs without wedge demonstrated greater improvements in static balance parameters under the more challenging conditions (eyes closed and/or soft surface) compared to wedged designs. These findings suggest that basic CFOs may be sufficient for managing pain in PF;

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however, if balance is a concern, then the selection of specific orthotic designs may be warranted.

INTRODUCTION

Plantar fasciitis (PF) is one of the most common causes of heel pain and is purported to affect approximately 10% of people during their lifetime.[1] It is characterized by inflammation or degeneration of the plantar fascia, a fibrous membrane that acts as a shock absorber and supports the longitudinal arch of the foot.[2] The plantar fascia plays a crucial role in the biomechanics of walking and running, supporting approximately 10%–14% of the total load of the foot and undergoing an elongation of approximately 9%–12% under total body weight during the contact phase of gait.[3]

Beyond the well-documented pain symptoms, PF significantly affects postural control and balance. Research has demonstrated that patients with PF exhibit significant alterations in both static and dynamic postural balance compared to healthy individuals.[4] One explanation for this is that when the plantar fascia is injured, sensorimotor function is disrupted, leading to alterations and issues in postural control. Specifically, individuals with PF often show impaired ankle joint position sense and reduced postural stability, such as increased mediolateral sway.[5,6] These deficits are compounded by weakness in the intrinsic foot muscles and ankle stabilizers, reduced gastrocnemius-soleus flexibility, and even altered activation of proximal hip muscles, all of which disrupt normal muscle patterns and challenge stability.[7–9] Furthermore, the biomechanical changes associated with PF further disrupt equilibrium. This includes a slower, more protective gait, altered multisegment foot motion like increased rearfoot or midfoot eversion, and a redistribution of plantar loading, which collectively impair the body's ability to maintain balance during standing and walking.[5,7,10]

These compensations alter joint position sense and muscle activation patterns that challenge the maintenance of postural stability.[11] Additionally, the biomechanical changes associated with PF, such as excessive foot pronation and altered weight distribution, further disrupt the body's ability to maintain equilibrium during standing and walking.[12,13]

Conservative management is the main treatment for PF, with >90% of patients responding to nonsurgical interventions.[14] Among these, foot orthoses are one of the most commonly used treatments.[15,16] Foot orthoses work through various mechanisms, including reducing tissue stress during standing and walking, providing arch support, redistributing plantar pressures, and potentially stimulating plantar mechanoreceptors.[17,18] These devices aim to correct biomechanical abnormalities, reduce excessive pronation, and decrease tension on the plantar fascia.[19]

Custom foot orthoses (CFOs) are designed to address individual biomechanical needs and have been shown to be effective in reducing pain and improving function in patients with PF.[20,21] Previous study has shown that orthotic wedges can alter lower-extremity and multisegment foot kinematics during gait in people with PF, potentially reducing the relative length of the plantar fascia and associated pain.[22] Beyond pain reduction, previous studies have highlighted the immediate and sustained benefits of CFOs on balance in individuals with PF. For example, research involving obese middle-aged women with PF found that CFOs significantly reduced pain and improved both static and dynamic postural balance from assessments of center of pressure (CoP) and Timed Up and Go (TUG).[22] In addition, Wrobel et al. reported that CFOs led to significant improvements in balance and postural transition duration compared to prefabricated foot orthoses and sham insoles in a randomized controlled trial, suggesting that CFOs may be particularly effective in enhancing weight-bearing function and stability.[18]

Among studies that have used objective measurements in patients with PF, most investigations have been limited to examining immediate effects or using pre-post study designs with short follow-up periods. For instance, Hammami et al.[22] investigated only the immediate impact of CFOs on postural balance and pain in middle-aged women with obesity and PF, showing significant immediate improvements in pain and balance parameters. Similarly, Harutaichun et al.[23] examined the immediate biomechanical effects of different orthotic wedge designs on lower-extremity and multisegment foot kinematics during gait but did not assess longer-term clinical outcomes. Longer follow-ups have been reported by Moyne-Bressand et al.[17] who evaluated neural adaptations over 9 weeks but focused primarily on neural strategy rather than balance measurements and Wrobel et al.[18] who conducted a randomized trial comparing CFOs, prefabricated foot orthoses, and sham insoles with a 3-month follow-up; however, they did not perform a detailed analysis of balance across different orthotic designs.

The effectiveness of CFOs in improving balance is closely linked to their design features. Finite element analyses have shown that higher arch support and medial inclination angles are particularly effective in reducing peak plantar pressure and plantar fascia strain.[24] Orthotic wedges, including forefoot and rearfoot varus wedges, can alter lower limb and multisegment foot kinematics, leading to changes in rearfoot inversion, forefoot dorsiflexion, and plantar fascia length during gait, all of which are factors associated with improved balance and reduced pain.[23,25] Despite the widespread use of foot orthoses with orthotic wedges, there remains a need

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for research directly comparing the effects of different CFO designs on balance and pain outcomes in PF with longer follow ups. Common clinical designs used include CFOs without wedge, CFOs with orthotic wedge type 1 (W1) based on the technique reported by Root et al.,[26] and CFOs with orthotic wedge type 2 (W2) based on the technique reported by Monaghan et al.[13] Understanding how specific design features influence postural control can inform clinical decision-making and optimize rehabilitation strategies for patients with balance impairments due to PF. Therefore, we conducted a randomized controlled trial with a longer follow-up period of 6 months to determine the effects of different designs of foot orthoses on pain and balance in individuals with PF.

METHODS

Study design

A randomized controlled trial was conducted to evaluate the effectiveness of three types of CFOs in individuals with PF. The study protocol was approved by the Center of Ethical Reinforcement for Human Research of Mahidol University (COA no. MU-CIRB 2023/013.0102). Additionally, the trial was prospectively registered on ClinicalTrials.gov (NCT06319066).

Study participants

Participants were included if they met the PF diagnostic criteria established by a physical therapist[15]: (1) tenderness upon palpation of the medial calcaneal tubercle and the medial aspect of the proximal portion of the plantar fascia, or pain along the plantar fascia at the medial longitudinal arch side; and (2) experienced heel pain immediately during the first few steps of walking in the morning or after a prolonged period of inactivity, with pain gradually decreasing throughout the day with ordinary walking, but worsening with prolonged activity. Additional inclusion criteria comprised participants aged 18–60 years, experiencing heel pain persisting for a minimum of 6 weeks (indicating a chronic condition),[27] and reporting a maximum pain intensity of at least 3 out of 10 on the visual analog scale during the previous week.

Participants were excluded if they (1) had a positive sciatica test, indicating L5-S1 nerve root irritation; (2) had a history of lower extremity fracture; (3) had a history of lower extremity surgery; or (4) had been diagnosed with gout, diabetic neuropathy, rheumatoid arthritis, systemic lupus erythematosus, cancer, or infectious disease.

Sample size calculation

The sample size was determined using G*Power software version 3.1.9.4. Based on a previous study comparing relative length of the plantar fascia during weight-bearing tasks among different foot orthoses conditions (shod: 4.71 ± 1.81, W1: 4.03 ± 1.47, W2: 3.90 ± 1.52),[23] we calculated a medium effect size (Cohen's $d = 0.36$) for the related outcome measures. With a significance level (α) of .05, power ($1 - \beta$) of 90%, and considering three groups (CFOs, W1, and W2), a total sample size of 120 participants (40 per group) was determined to be sufficient to detect significant differences in gait parameters. This sample size also accounted for a potential dropout rate of approximately 15%.

Interventions

The CFOs were prescribed and fitted by the therapist with >10 years of clinical experience in managing musculoskeletal conditions using foot orthoses. Each CFO was heat-molded individually while the participant was in a prone position, following the contour of the foot. The orthoses consisted of a dual-layer thermoplastic structure: a three-quarter-length base layer made of 3-mm polycaprolactone to provide structural support and customization, and a full-length top layer of ethylene propylene diene monomer rubber to enhance cushioning and comfort. Additionally, the design incorporated a medial arch support and heel padding (Figure 1).

In addition, two types of orthotic wedges were manufactured for this study:

1. Orthotic wedge type 1 (W1): Based on the traditional foot assessment technique reported by Root et al.,[26] with posting at 60% of the measured forefoot angle (up to a maximum of 8°), extrinsic forefoot varus wedge and posting at 50% of the measured forefoot angle (up to a maximum of 6°), and an extrinsic rearfoot varus wedge.
2. Orthotic wedge type 2 (W2): Based on the foot assessment technique reported by Monaghan et al.,[13] with the forefoot posted at 50% of the measured forefoot angle and the rearfoot posted at 20% of the measured rearfoot angle.

The wedges were made from solid rubber with a thin fabric cover and were available in three sizes for forefoot posting (3°, 6°, and 8°) and two sizes for rearfoot posting (3° and 6°). The CFO group received heat-molded orthoses without wedges, whereas the W1 group was fitted with orthoses and wedges according to the assessment technique by Root et al.,[26] and the W2 group received orthoses and wedges based on the assessment technique by Monaghan et al.[13]

Outcome measures

Outcome measures included pain intensity and dynamic and static balance, which were assessed at

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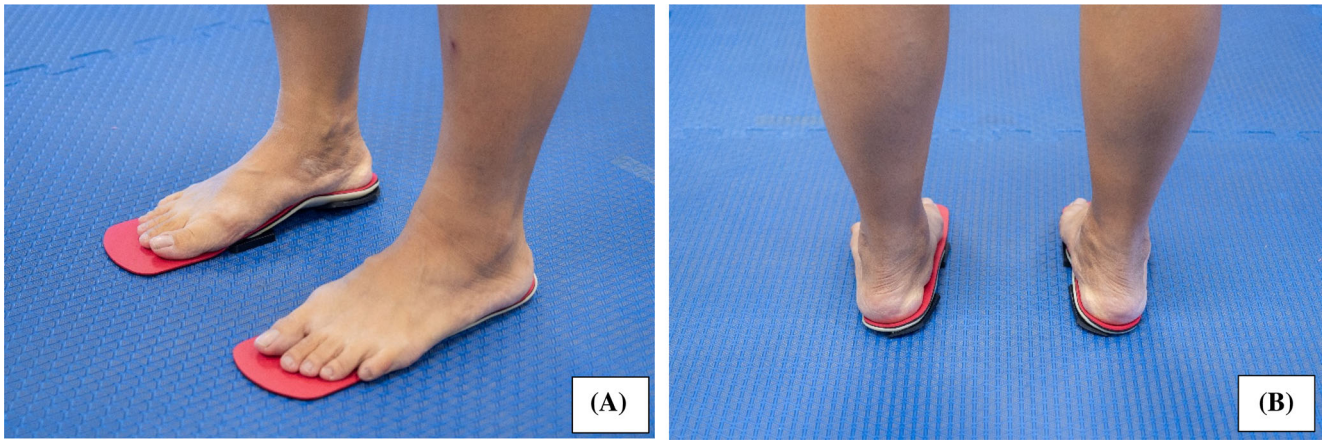


FIGURE 1 Custom foot orthoses used in the present study (1A: superior view; 1B: posterior view).

baseline, 3-month, and 6-month follow-up by the investigator who was blinded to group allocation. Using the visual analog scale, pain intensity was evaluated at each assessment point, measuring the average pain during the previous week across multiple domains: daily worst pain, morning pain, standing-related pain, and walking-induced pain. In addition, dynamic balance was assessed using the Y Balance Test (YBT). Participants performed three trial attempts in the anterior, posteromedial, and posterolateral directions, and the average reach distance for each direction was calculated and normalized to leg length.[28] Static balance was assessed using a force distribution measurement platform (Zebris Medical GmbH, Germany). Participants maintained a quiet stance for 30 seconds with their feet shoulder-width apart and arms relaxed by their sides under four conditions: eyes open on a firm surface (EOFS), eyes closed on a firm surface (ECFS), eyes open on a soft surface (EOSS), and eyes closed on a soft surface (ECSS). Measures from the static balance tests included the length of the minor axis (mm) which corresponded to medial-lateral sway, and length of the major axis (mm), which corresponded to anterior–posterior sway, 95% confidence ellipse area (CEA) (mm^2), CoP path length (mm), and CoP average velocity (mm/s).[5]

Research procedure

Eligible participants underwent a baseline assessment including recording demographic data and foot postures. This assessment included age, gender, body mass index (BMI), weight-bearing hours per day, heel pain duration, and the number of participants with abnormal foot posture (ie, supinated and pronated feet) from the foot posture index.[29]

In participants with bilateral PF, the more symptomatic limb was selected for evaluation. Participants were then randomly allocated into three treatment groups by the therapist using a computer-generated randomization sequence and opaque sealed envelopes: (1) CFOs without wedge, (2) CFO W1, and (3) CFO W2. All participants were instructed to use their assigned CFOs during daily weight-bearing activities for at least 4 hours per day, with compliance monitored through logbooks, chat line, or phone calls.

Statistical analysis

Statistical analysis was performed using intention-to-treat principles. Descriptive statistics were calculated for all variables. For normally distributed data, a 3×3 mixed model ANOVA was used to determine differences between the three groups (CFOs without wedge, CFO W1, CFO W2) over the three time points (baseline, 3 months, and 6 months). Where significant main effects were seen, post-hoc pairwise comparisons with Bonferroni corrections were performed. For nonnormally distributed data, the Kruskal–Wallis test was used to determine between-group differences, and the Friedman test was used to determine within-group differences over the three time points. All statistical analyses were performed using SPSS software version 22.0 (IBM Statistics), with a statistical significance level set to $p < .05$.

RESULTS

Figure 2 illustrates the flow of participants throughout the study. One participant in the CFO group dropped out due to discomfort but was included in the final analysis using the last observation carried forward. The mean age of participants was 44.3 ± 10.1 years with a mean BMI of 26.5 ± 4.9 kg/m^2. The sample consisted of 33 (27.5%) males and 87 (72.5%) females. There

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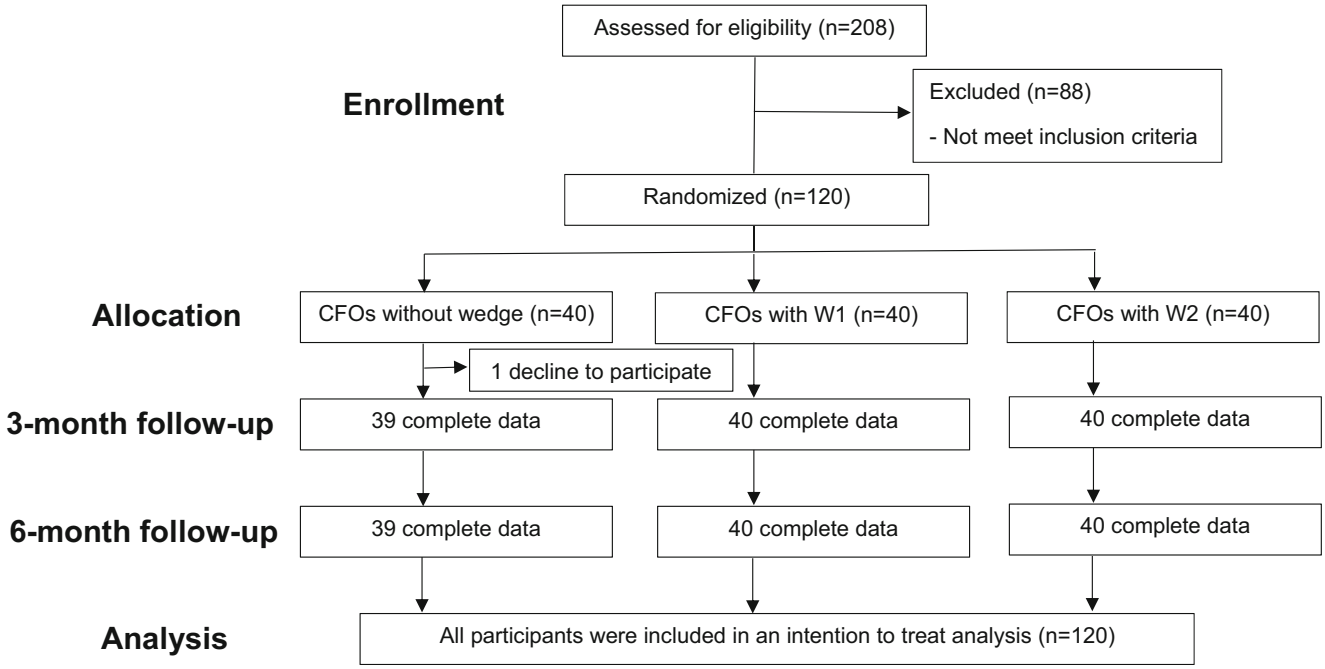


FIGURE 2 Flow chart in the present study. CFO, custom foot orthoses; W1, orthotic wedge type 1; W2, orthotic wedge type 2.

were no significant differences in baseline characteristics between groups including age, BMI, gender, standing duration, heel pain duration ($p > .05$) and baseline measures of pain intensity and dynamic and static balance ($p > .05$) (Table 1). However, a significant difference was observed in the individuals with abnormal foot posture, with supinated feet being more common in the CFOs without wedge group (27.5%) compared to W1 (12.5%) and W2 (2.5%) groups ($p < .05$). All three groups wore the foot orthoses with similar frequency, with a mean percentage of wearing days of 70.71 ± 20.52 (CFOs without wedge: 73.75 ± 18.79, CFO W1: 70.58 ± 20.64, CFO W2: 67.81 ± 22.14, $p = .442$) during the 6-month follow-up period.

Pain intensity

There was significant difference in the worst pain between groups, with the lowest pain level seen in the CFOs group at 3-month and 6-month follow ups ($p = .037$ and $p = .039$, respectively) (Table 1). All three groups showed significant reduction in the worst pain, morning pain, pain during gait, and pain during standing over the three time points ($p < .001$) (Table 2, Figure 3). When comparing the mean/median changes from baseline to 6-month follow-up between the three groups, no significant differences were found for any pain parameters (all $p > .05$) (Table 3).

Dynamic balance from YBT

There was no significant group × time interaction in the symptomatic side ($F_{(4,232)} = 0.193$, $p = .942$, effect size = 0.110) and in the asymptomatic side ($F_{(4,232)} = 0.864$, $p = .486$, effect size = .247) (Table 1). All three groups demonstrated significant improvements in dynamic balance for both symptomatic and nonsymptomatic sides over the three time points ($p < .01$) (Table 2, Figure 4). No significant differences were found among the three groups when comparing the median changes from baseline to 6-month follow-up ($p > .05$) (Table 3).

Static balance parameters

No significant differences were found between groups at the different time points for overall static balance parameters (Table 1). In the ECFS condition, within-group analysis of the CFOs group revealed significant improvements in medial-lateral sway ($p = .029$), anterior–posterior sway ($p = .020$), and 95% CEA ($p = .029$) (Table 2, Figures 5A and 6A). When comparing mean/median changes from baseline to follow-up, between-group analysis showed significant differences in medial-lateral sway ($p = .005$) and 95% CEA ($p = .006$), with the CFOs group demonstrating significantly better improvement compared to the W2 group (medial-lateral sway $p = .004$; 95% CEA $p = .002$) (Table 3).

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TABLE 1 Comparisons of the mean (SD) or median (IQR) of each outcome among the CFOs without wedge, CFOs with W1, and CFOs with W2 at each time point (between-group analysis) ($n = 120$).

	Baseline					3-mo follow-up					6-mo follow-up				
	Mean (SD)/median (IQR)					Mean (SD)/median (IQR)					Mean (SD)/median (IQR)				
	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	Effect size	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	Effect size	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	Effect size
Worst pain, cm	4.8 (1.8)	3.8 (1.9)	5.1 (2.3)	.182	0.346	1.5 [0.3–3.0]	2.4 [0.7–3.8]	2.9 [2.1–4.1]	**.037***	0.484	0.8 [0.0–2.2]	1.1 [0.2–2.4]	1.9 [0.9–3.3]	**.009***	0.585
Morning pain, cm	3.6 (2.1)	3.6 (2.4)	4.5 (2.7)	.164	0.364	1.4 [0.2–2.9]	1.4 [0.9–3.2]	2.7 [1.8–3.7]	.064	0.438	0.6 [0.0–1.4]	0.7 [0.0–2.0]	1.4 [0.4–3.1]	.056	0.449
Pain during gait, cm	4.4 (2.1)	4.7 (2.1)	5.2 (2.4)	.660	0.168	1.7 [0.9–4.8]	2.4 [0.9–4.0]	2.8 [1.6–4.1]	.647	0.171	0.9 [0.3–2.0]	1.2 [0.4–2.3]	1.8 [0.9–4.1]	.064	0.438
Pain during standing, cm	4.2 (1.9)	4.4 (2.3)	4.7 (2.5)	.700	0.155	1.9 [0.8–3.4]	2.3 [1.0–3.9]	2.6 [1.3–3.9]	.445	0.234	0.6 [0.2–2.2]	1.6 [0.3–2.4]	1.6 [0.4–2.9]	.096	0.403
Reaching distance, cm															
Symptomatic side[a]	69.39 (12.84)	69.79 (8.37)	69.63 (8.79)	.870	0.090	74.72 (12.32)	73.81 (8.54)	71.92 (11.04)	.636	0.180	76.02 (12.40)	74.50 (9.33)	74.54 (12.09)	.779	0.127
Asymptomatic side[b]	68.42 (12.68)	70.90 (9.89)	69.73 (9.92)	.985	0.035	74.43 (10.20)	74.74 (9.41)	71.20 (10.56)	.310	0.286	75.03 (12.79)	74.05 (11.02)	74.51 (11.71)	.934	0.063
ECFS condition															
Length of minor axis, mm	4.7 [3.2–5.8]	4.0 [3.1–5.3]	4.4 [2.8–5.7]	.150	0.361	4.3 [3.3–5.4]	4.3 [3.2–6.1]	4.9 [3.3–6.1]	.780	0.130	4.8 (2.2)	4.5 (1.7)	4.9 (1.7)	.532	0.209
Length of major axis, mm	11.7 [9.2–13.7]	11.0 [9.1–13.2]	11.2 [8.0–12.9]	.187	0.340	10.5 [8.3–15.3]	10.6 [8.7–12.8]	10.4 [8.1–14.3]	.565	0.197	11.0 [8.7–12.8]	10.4 [8.6–12.8]	10.1 [7.8–11.5]	.757	0.138
95% CEA, mm^2	36.6 [26.2–52.7]	37.9 [21.1–56.5]	36.9 [19.1–58.9]	.139	0.377	34.6 [23.1–60.1]	36.5 [21.6–68.3]	46.8 [23.8–69.0]	.700	0.157	32.4 [21.5–64.2]	32.6 [23.5–49.2]	38.7 [28.4–48.9]	.956	0.055
CoP path length, mm	113.5 [97.2–145.6]	113.3 [94.7–158.1]	115.8 [85.5–174.1]	.541	0.204	102.6 [82.9–156.1]	132.3 [97.3–163.7]	113.8 [90.0–144.2]	.544	0.204	113.5 [84.8–152.6]	125.0 [103.1–156.0]	102.4 [94.9–119.6]	.748	0.141
CoP velocity, mm/s	5.5 [4.9–7.1]	5.8 [4.8–7.8]	5.9 [4.3–8.0]	.604	0.184	5.2 [4.2–8.0]	5.8 [4.9–8.3]	5.8 [4.6–7.3]	.808	0.121	5.8 [4.3–7.8]	6.4 [5.3–8.0]	5.2 [4.4–6.1]	.727	0.148
ECSS condition															
Length of minor axis, mm	25.0 (8.4)	23.5 (7.5)	22.7 (7.2)	.513	0.211	24.2 [17.7–28.3]	21.1 [19.0–27.3]	20.8 [16.8–27.3]	.381	0.258	21.7 [15.8–26.5]	24.0 [16.9–26.8]	22.1 [18.8–27.4]	.732	0.146
Length of major axis, mm	40.3 [36.6–51.8]	38.3 [31.4–53.2]	37.2 [34.4–43.3]	.429	0.240	38.0 [29.0–50.6]	39.2 [29.2–47.0]	36.0 [30.1–44.6]	.512	0.215	34.6 [30.0–45.1]	41.9 [30.5–46.0]	38.0 [29.0–46.8	.320	0.281

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TABLE 1 (Continued)

	Baseline					3-mo follow-up					6-mo follow-up				
	Mean (SD)/median (IQR)					Mean (SD)/median (IQR)					Mean (SD)/median (IQR)				
	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	Effect size	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	Effect size	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	Effect size
95% CEA, mm^2	765.1 [554.8–1245.5]	787.2 [423.8–1084.4]	691.2 [536.8–787.8]	.322	0.284	639.2 [406.5–1209.3]	616.0 [462.6–995.7]	592.5 [410.9–1043.4]	.561	0.200	614.4 [337.1–918.8]	734.8 [442.0–1009.6]	667.6 [407.5–945.8]	.620	0.183
CoP path length, mm	802.6 [709.3–1280.5]	873.1 [690.9–1070.1]	786.7 [660.4–1051.5]	.924	0.074	692.2 [548.4–1068.8]	875.3 [656.5–1111.6]	752.4 [619.1–1318.2]	.787	0.128	780.5 [577.5–993.4]	864.2 [743.6–1047.0]	736.5 [549.8–1011.4]	.482	0.228
CoP velocity, mm/s	39.7 [34.9–62.4]	44.2 [33.4–54.2]	39.5 [30.6–61.5]	.763		32.2 [27.9–54.4]	44.6 [33.4–56.6]	38.3 [31.5–67.1]	.786	0.129	39.7 [29.4–50.6]	44.0 [37.9–53.3]	37.5 [28.0–51.5]	.488	0.226
EOFS condition															
Length of minor axis, mm	4.3 [3.8–5.4]	3.8 [2.9–5.3]	4.2 [3.2–5.9]	.117	0.387	4.8 [3.0–6.6]	4.7 [3.4–6.9]	4.7 [3.6–6.4]	.860	0.102	5.1 [3.7–6.2]	4.7 [3.5–6.0]	4.8 [4.0–6.3]	.828	0.114
Length of major axis, mm	10.1 (2.5)	10.0 (2.6)	10.2 (2.9)	.065	0.444	10.1 [8.6–12.8]	10.9 [7.3–12.7]	9.2 [7.3–13.0]	.374	0.259	12.1 [9.6–13.4]	10.3 [7.8–14.0]	9.9 [7.6–12.2]	.273	0.299
95% CEA, mm^2	37.3 [25.3–46.1]	30.4 [19.6–48.9]	33.9 [18.8–57.3]	.101	0.411	35.0 [24.7–65.2]	38.2 [19.8–73.4]	32.7 [21.0–68.8]	.786	0.130	46.6 [33.6–70.2]	40.0 [23.4–70.3]	38.8 [23.6–61.9]	.814	0.119
CoP path length, mm	87.0 [75.71–04.0]	84.8 [69.8–115.9]	98.4 [75.5–130.7]	.476	0.224	90.0 [73.6–120.7]	107.0 [80.7–139.4]	96.3 [64.1–130.8]	.518	0.212	105.3 [79.8–122.7]	99.4 [79.8–131.3]	90.7 [72.8–116.7]	.752	0.140
CoP velocity, mm/s	4.4 [3.7–5.2]	4.3 [3.6–5.8]	5.0 [3.7–6.5]	.657	0.168	4.6 [3.8–6.2]	5.1 [4.1–6.7]	4.9 [3.3–6.7]	.695	0.157	5.4 [4.1–6.3]	5.1 [4.1–6.7]	4.6 [3.7–5.7]	.783	0.129
EOSS condition															
Length of minor axis, mm	19.8 (6.8)	18.0 (7.1)	18.1 (5.5)	.356	0.278	18.7 [13.7–21.9]	17.2 [15.5–19.3]	18.3 [13.6–23.4]	.568	0.198	16.7 [13.6–21.2]	16.8 [13.4–22.1]	18.2 [13.0–24.2]	.964	0.050
Length of major axis, mm	33.5 [27.5–45.3]	31.1 [24.6–38.2]	24.2 [29.5–37.4]	.326	0.280	33.8 [24.6–43.0]	30.2 [24.8–37.2]	28.2 [24.1–38.0]	.430	0.243	29.2 [23.8–38.7]	30.9 [26.5–40.1]	29.9 [23.7–40.0]	.514	0.215
95% CEA, mm^2	530.7 [342.2–805.9]	449.6 [295.1–628.9]	437.1 [250.9–684.0]	.317	0.287	550.5 [292.2–744.4]	415.6 [331.6–616.4]	414.0 [293.3–756.6]	.506	0.220	350.7 [266.1–681.0]	443.9 [273.1–650.5]	439.8 [215.8–736.4]	.777	0.133
CoP path length, mm	597.7 [456.9–975.5]	631.5 [549.6–793.8]	556.5 [464.3–778.9]	.898	0.086	25.9 [18.7–44.8]	34.9 [24.7–39.7]	28.6 [21.8–49.6]	.888	0.091	559.0 [388.8–778.7]	634.4 [461.5–753.1]	573.7 [388.8–729.5]	.432	0.242

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TABLE 1 (Continued)

	Baseline				3-mo follow-up				6-mo follow-up			
	Mean (SD)/median (IQR)				Mean (SD)/median (IQR)				Mean (SD)/median (IQR)			
	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value	CFOs without wedge	CFOs with W1	CFOs with W2	*p* value
CoP velocity, mm/s	29.4 [21.2–48.6]	32.2 [24.8–40.4]	27.8 [21.8–39.7]	.624	508.9 [367.8–878.4]	685.8 [485.6–782.5]	561.0 [429.4–974.6]	.889	28.5 [19.8–39.7]	32.3 [23.5–38.3]	29.2 [19.8–37.1]	.428
Effect size				0.181				0.091				0.244

[a]No significant group × time interaction ($F_{(4,232)} = 0.193$, $p = .942$, effect size = 0.110).
[b]No significant group × time interaction ($F_{(4,232)} = 0.864$, $p = .486$, effect size = 0.247).
*Significant difference among three intervention groups.
Abbreviations: CEA, confidence ellipse area; CFO, custom foot orthoses; ECFS, eyes closed, firm surface; ECSS, eyes closed, soft surface; EOFS, eyes open, firm surface; EOSS, eyes open, soft surface; IQR, interquartile range; W1, orthotic wedge type 1; W2, orthotic wedge type 2.

In the ECSS condition, within-group analysis showed the CFOs group improved in medial-lateral sway ($p = .019$), anterior–posterior sway ($p = .003$), 95% CEA ($p < .001$), CoP path length ($p < .001$), and CoP velocity ($p = .013$). The W1 group improved in CoP path length ($p = .045$) and velocity ($p = .045$), whereas the W2 group improved only in medial-lateral sway ($p = .039$) (Table 2, Figures 5B and 6B). Between-group analysis of mean/median changes revealed a significant difference in 95% CEA ($p = .042$), with the CFOs group showing significantly better improvement compared to the W1 group ($p = .020$) (Table 3).

In the EOFS condition, within-group analysis showed the W2 group experienced significant increases in medial-lateral sway ($p < .001$) and 95% CEA ($p = .020$) (Table 2, Figure 5C), indicating performance deterioration. Conversely, within-group analysis showed no significant difference in anterior–posterior sway across any groups ($p > .05$) (Table 2, Figure 6C). Between-group analysis of mean/median changes found significant differences in medial-lateral sway ($p = .008$) and 95% CEA ($p = .037$), with the W2 group showing significantly increased values compared to the CFOs group (medial-lateral sway $p = .004$; 95% CEA $p = .012$) (Table 3).

In the EOSS condition, within-group analysis of the CFOs group showed improvements in medial-lateral sway ($p = .047$), anterior–posterior sway ($p = .028$), 95% CEA ($p = .029$), CoP path length ($p = 0.013$), and CoP velocity ($p = .041$) (Table 2, Figures 5D and 6D). Between-group analysis of mean/median changes revealed significant differences in 95% CEA ($p = .015$) and CoP path length ($p = .013$), with the CFOs group showing significantly better improvement compared to both W1 ($p = .008$) and W2 (95% CEA $p = .018$; CoP path length $p = .014$) groups (Table 3).

Overall, all three interventions were effective in reducing pain and improving reach distance measured using the YBT, with varying effects on static balance parameters. The CFOs without wedge showed more consistent improvements in static balance parameters, particularly under challenging conditions (eyes closed and/or soft surface), while the CFOs with wedges (W1 and W2) showed selective improvements in some static balance parameters.

DISCUSSION

The present study investigated the effects of different types of CFOs (CFOs without wedge, CFO W1, and CFO W2) on pain intensity, dynamic balance measured using the YBT, and static balance parameters in individuals with PF. Our findings demonstrated significant improvements in outcomes across all three intervention

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TABLE 2 Comparisons of the mean (SD) or median (IQR) of each outcome at baseline, 3-month, and 6-month follow-up among each intervention group (within-group analysis) ($n = 120$).

	CFOs without wedge					CFOs with W1					CFOs with W2				
	Mean (SD)/median (IQR)				Effect	Mean (SD)/median (IQR)				Effect	Mean (SD)/median (IQR)				Effect
	Baseline	3 month	6 month	*p* value	size	Baseline	3 mo	6 mo	*p* value	size	Baseline	3 mo	6 mo	*p* value	size
Worst pain, cm	4.4 [3.5–6.8]	1.5 [0.3–3.0]	0.8 [0.0–2.2]	**< .001***	6.954	4.6 [3.4–5.2]	2.4 [0.7–3.8]	1.1 [0.2–2.4]	**< .001***	13.638	4.4 [3.3–7.1]	2.9 [2.1–4.1]	1.9 [0.9–3.3]	**< .001***	1.976
Morning pain, cm	3.5 [1.7–4.9]	1.4 [0.2–2.9]	0.6 [0.0–1.4]	**< .001***	2.486	3.8 [1.8–5.5]	1.4 [0.9–3.2]	0.7 [0.0–2.0]	**< .001***	11.995	3.8 [1.9–6.1]	2.7 [1.8–3.7]	1.4 [0.4–3.1]	**.003***	1.309
Pain during gait, cm	5.2 [3.1–6.5]	1.7 [0.9–4.8]	0.9 [0.3–2.0]	**< .001***	13.820	4.6 [3.0–5.4]	2.4 [0.9–4.0]	1.2 [0.4–2.3]	**< .001***	15.790	4.7 [3.6–7.3]	2.8 [1.6–4.1]	1.8 [0.9–4.1]	**< .001***	2.447
Pain during standing, cm	4.7 [2.9–6.0]	1.9 [0.8–3.4]	0.6 [0.2–2.2]	**< .001***	12.829	4.5 [2.9–5.4]	2.3 [1.0–3.9]	1.6 [0.3–2.4]	**< .001***	12.845	4.6 [2.1–6.0]	2.6 [1.3–3.9]	1.6 [0.4–2.9]	**< .001***	1.778
Reaching distance, cm															
Symptomatic side[a]	69.39 (12.84)	74.72 (12.32)	76.02 (12.40)	**.001***	0905	69.79 (8.37)	73.81 (8.54)	74.50 (9.33)	**< .001***	1.006	69.63 (8.79)	71.92 (11.04)	74.54 (12.09)	**< .001***	0.940
Asymptomatic side[b]	68.42 (12.68)	74.43 (10.20)	75.03 (12.79)	**< .001***	0.991	70.90 (9.89)	74.74 (9.41)	74.05 (11.02)	**.003***	0.797	69.73 (9.92)	71.20 (10.56)	74.51 (11.71)	**< .001***	1.176
ECFS condition															
Length of minor axis, mm	4.7 [3.2–5.8]	4.3 [3.3–5.4]	4.4 [3.1–6.3]	**.029***	0.940	4.0 [3.1–5.3]	4.3 [3.2–6.1]	4.3 [3.3–5.7]	.885	0.159	4.4 [2.8–5.7]	4.9 [3.3–6.1]	5.0 [3.7–6.1]	.153	0.643
Length of major axis, mm	11.7 [9.2–13.7]	10.5 [8.3–15.3]	11.0 [8.7–12.8]	**.020***	1.017	11.0 [9.1–13.2]	10.6 [8.7–12.8]	10.4 [8.6–12.8]	.100	0.743	11.2 [8.0–12.9]	10.4 [8.1–14.3]	10.1 [7.8–11.5]	.741	0.247
95% CEA, mm^2	36.6 [26.2–52.7]	34.6 [23.1–60.1]	32.4 [21.5–64.2]	**.029***	0.991	37.9 [21.1–56.5]	36.5 [21.6–68.3]	32.6 [23.5–49.2]	.307	0.530	36.9 [19.1–58.9]	46.8 [23.8–69.0]	38.7 [28.4–48.9]	.649	0.309
CoP path length, mm	113.5 [97.2–145.6]	102.6 [82.9–156.1]	113.5 [84.8–152.6]	.063	0.825	113.3 [94.7–158.1]	132.3 [97.3–163.7]	125.0 [103.1–156.0]	.729	0.257	115.8 [85.5–174.1]	113.8 [90.0–144.2]	102.4 [94.9–119.6]	.735	0.253
CoP velocity, mm/s	5.5 [4.9–7.1]	5.2 [4.2–8.0]	5.8 [4.3–7.8]	.215	0.585	5.8 [4.8–7.8]	5.8 [4.9–8.3]	6.4 [5.3–8.0]	.898	0.151	5.9 [4.3–8.0]	5.8 [4.6–7.3]	5.2 [4.4–6.1]	.691	0.278
ECSS condition															
Length of minor axis, mm	26.2 [18.4–34.7]	24.2 [17.7–28.3]	21.7 [15.8–26.5]	**.019***	1.009	24.6 [18.3–28.6]	21.1 [19.0–27.3]	24.0 [16.9–26.8]	.557	0.347	24.5 [15.2–30.0]	20.8 [16.8–27.3]	22.1 [18.8–27.4]	**.039***	0.900
Length of major axis, mm	40.3 [36.6–51.8]	38.0 [29.0–50.6]	34.6 [30.0–45.1]	**.003***	1.340	38.3 [31.4–53.2]	39.2 [29.2–47.0]	41.9 [30.5–46.0]	.822	0.199	37.2 [34.4–43.3]	36.0 [30.1–44.6]	38.0 [29.0–46.8	.232	0.569
95% CEA, mm^2	765.1 [554.8–1245.5]	639.2 [406.5–1209.3]	614.4 [337.1–918.8]	**< .001***	1.999	787.2 [423.8–1084.4]	616.0 [462.6–995.7]	734.8 [442.0–1009.6]	.993	0.040	691.2 [536.8–787.8]	592.5 [410.9–1043.4]	667.6 [407.5–945.8]	.388	0.458
CoP path length, mm	802.6 [709.3–1280.5]	692.2 [548.4–1068.8]	780.5 [577.5–993.4]	**< .001***	1.647	873.1 [690.9–1070.1]	875.3 [656.5–1111.6]	864.2 [743.6–1047.0]	**.045***	0.884	786.7 [660.4–1051.5]	752.4 [619.1–1318.2]	736.5 [549.8–1011.4]	.135	0.686

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TABLE 2 (Continued)

	CFOs without wedge					CFOs with W1					CFOs with W2				
	Mean (SD)/median (IQR)				Effect	Mean (SD)/median (IQR)				Effect	Mean (SD)/median (IQR)				Effect
	Baseline	3 month	6 month	*p* value	size	Baseline	3 mo	6 mo	*p* value	size	Baseline	3 mo	6 mo	*p* value	size
CoP velocity, mm/s	39.7 [34.9–62.4]	32.2 [27.9–54.4]	39.7 [29.4–50.6]	**.013***	1.090	44.2 [33.4–54.2]	44.6 [33.4–56.6]	44.0 [37.9–53.3]	**.049***	0.794	39.5 [30.6–61.5]	38.3 [31.5–67.1]	37.5 [28.0–51.5]	.479	0.402
EOFS condition															
Length of minor axis, mm	4.3 [3.8–5.4]	4.8 [3.0–6.6]	5.1 [3.7–6.2]	.432	0.436	3.8 [2.9–5.3]	4.7 [3.4–6.9]	4.7 [3.5–6.0]	.697	0.271	4.20 [3.23–5.93]	4.7 [3.6–6.4]	4.8 [4.0–6.3]	**< .001***	1.643
Length of major axis, mm	10.4 [7.9–13.3]	10.1 [8.6–12.8]	12.1 [9.6–13.4]	.668	0.295	9.7 [7.8–11.7]	10.9 [7.3–12.7]	10.3 [7.8–14.0]	.782	0.223	9.7 [8.0–12.6]	9.2 [7.3–13.0]	9.9 [7.6–12.2]	.172	0.630
95% CEA, mm^2	37.3 [25.3–46.1]	35.0 [24.7–65.2]	46.6 [33.6–70.2]	.831	0.210	30.4 [19.6–48.9]	38.2 [19.8–73.4]	40.0 [23.4–70.3]	.193	0.635	33.9 [18.8–57.3]	32.7 [21.0–68.8]	38.8 [23.6–61.9]	**.020***	1.032
CoP path length, mm	87.0 [75.7–104.0]	90.0 [73.6–120.7]	105.3 [79.8–122.7]	.322	0.504	84.9 [69.8–115.9]	107.0 [80.7–139.4]	99.4 [79.8–131.3]	.681	0.280	98.4 [75.5–130.7]	96.3 [64.11–30.8]	90.7 [72.8–116.7]	.488	0.391
CoP velocity, mm/s	4.4 [3.7–5.2]	4.6 [3.8–6.2]	5.4 [4.1–6.3]	.545	0.363	4.3 [3.6–5.8]	5.1 [4.1–6.7]	5.1 [4.1–6.7]	.792	0.217	5.0 [3.7–6.5]	4.9 [3.3–6.7]	4.6 [3.7–5.7]	.392	0.443
EOSS condition															
Length of minor axis, mm	18.2 [15.4–26.1]	18.7 [13.7–21.9]	16.7 [13.6–21.2]	**.047***	0.877	19.1 [13.2–23.7]	17.2 [15.5–19.3]	16.8 [13.4–22.1]	.823	0.199	18.7 [13.6–24.2]	18.3 [13.6–23.4]	18.2 [13.0–24.2]	.836	0.193
Length of major axis, mm	33.5 [27.5–45.3]	33.8 [24.6–43.0]	29.2 [23.8–38.7]	**.028***	0.978	31.1 [24.6–38.2]	30.2 [24.8–37.2]	30.9 [26.5–40.1]	.175	0.618	24.2 [29.5–37.4]	28.2 [24.1–38.0]	29.9 [23.7–40.0]	.442	0.424
95% CEA, mm^2	530.7 [342.2–805.9]	550.5 [292.2–744.4]	350.7 [266.1–681.0]	**.029***	0.991	449.6 [295.1–628.9]	415.6 [331.6–616.4]	443.9 [273.1–650.5]	.584	0.346	437.1 [250.9–684.0]	414.0 [293.3–756.6]	439.8 [215.8–736.4]	.779	0.237
CoP path length, mm	597.7 [456.9–975.5]	508.9 [367.8–878.4]	559.0 [388.8–778.7]	**.013***	1.090	631.5 [549.6–793.8]	685.8 [485.6–782.5]	634.4 [461.5–753.1]	.074	0.785	556.5 [464.3–778.9]	561.0 [429.4–974.6]	573.7 [388.8–729.5]	.518	0.379
CoP velocity, mm/s	29.4 [21.2–48.6]	25.9 [18.7–44.8]	28.5 [19.8–39.7]	**.041***	0.913	32.2 [24.8–40.4]	34.9 [24.7–39.7]	32.3 [23.5–38.3]	.097	0.737	27.8 [21.8–39.7]	28.6 [21.8–49.6]	29.2 [19.8–37.1]	.898	0.153

[a]No significant group × time interaction ($F_{(4,232)} = 0.193$, $p = .942$, effect size = 0.110).
[b]No significant group × time interaction ($F_{(4,232)} = 0.864$, $p = .486$, effect size = 0.247).
*Significant difference among baseline, 3-mo, and 6-mo follow up.
Abbreviations: CEA, confidence ellipse area; CFOs, custom foot orthoses; CoP, center of pressure; ECFS, eyes closed, firm surface; ECSS, eyes closed, soft surface; EOFS, eyes open, firm surface; EOSS, eyes open, soft surface; IQR, interquartile range; W1, orthotic wedge type 1; W2, orthotic wedge type 2.

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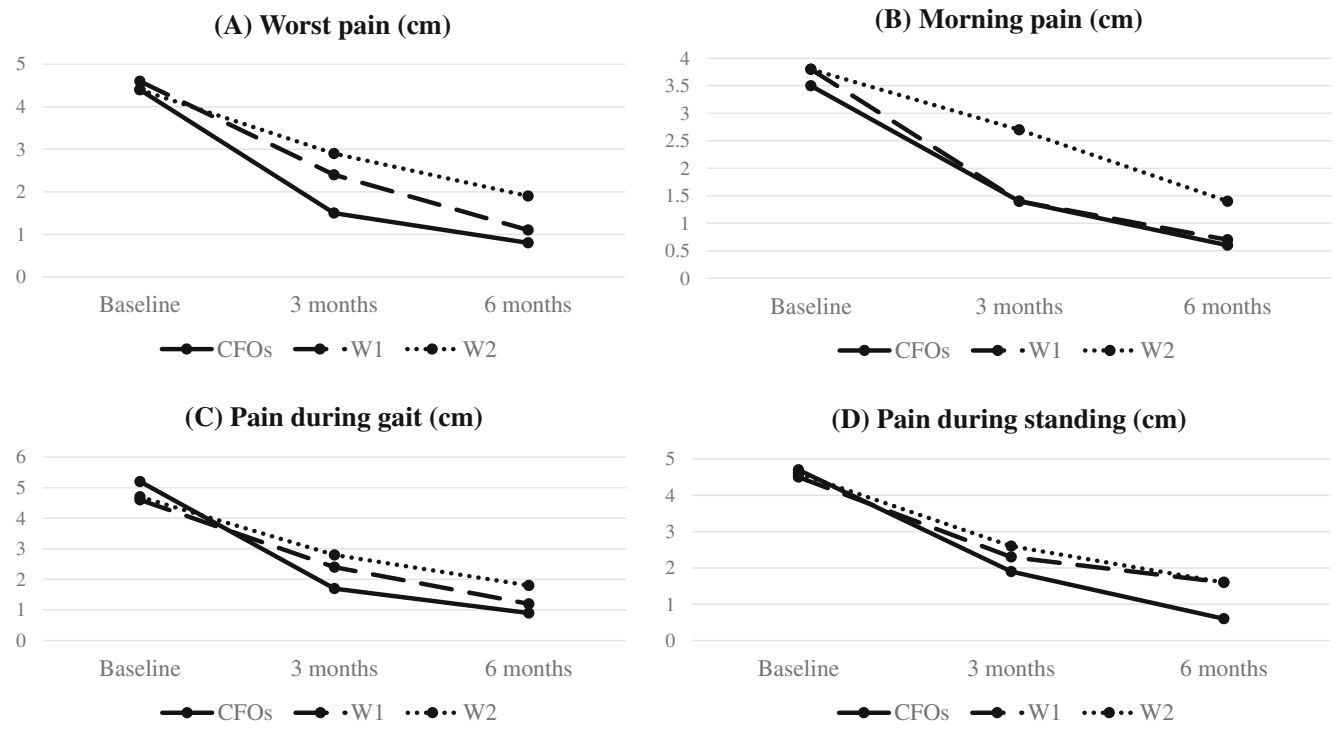


FIGURE 3 Between- and within-group comparison of pain intensity (cm): (A) Worst pain, (B) Morning pain, (C) Pain during gait, (D) Pain during standing. CFOs, custom foot orthoses.

groups, with notable differences in static balance parameters between groups.

Pain intensity

All three intervention groups showed significant reductions in pain intensity over the 6-month follow-up period. Notably, the CFOs without wedge group experienced significant pain reduction at 3-month and 6-month follow-up comparable to the groups with wedged orthoses. This suggests that the CFOs without additional wedging were as effective as wedged orthoses in alleviating pain for individuals with PF, with the wedge modifications offering no significant additional benefits in pain relief.

Previous studies on foot orthoses for PF were predominantly short-term (3–12 weeks) with smaller sample sizes.[18,21,30] The present study provided a comprehensive 6-month evaluation using 120 participants, systematically examining multiple orthotic designs and their long-term effects. The consistent pain reduction across intervention groups over 6 months suggests that mechanical support is crucial, and the specific orthotic configuration may be less critical than previously believed.[23] The pain reduction observed in the present study may be attributed to the mechanical effects of orthoses, which help redistribute plantar pressures and reduce tension on the plantar fascia.[31]

Dynamic balance from YBT

All three groups demonstrated significant improvements in dynamic balance for both symptomatic and nonsymptomatic sides. This improvement in reaching distance may be related to the reduction in pain, allowing individuals to perform the test with greater confidence and less discomfort. Such improvement suggests that foot orthoses may enhance dynamic balance and functional mobility in individuals with PF.

Foot orthoses, especially custom designs, are increasingly recognized for their role in improving dynamic balance in individuals with PF. Dynamic balance is commonly assessed using tests such as the YBT or the TUG test. CFOs have been shown to significantly and immediately improve dynamic balance in individuals with PF. In a study of middle-aged women with obesity and PF, CFOs led to significant improvements in TUG test scores compared to standard insoles and barefoot conditions, indicating enhanced dynamic postural control.[22]

Although direct studies using the YBT in PF have been limited, related dynamic balance measures, such as TUG test and modified star excursion balance test, showed that interventions targeting foot mechanics—including orthoses—could improve dynamic balance performance.[22,32] The improvements might attribute to pain reduction, better foot alignment, and enhanced proprioceptive feedback provided by the orthoses,

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TABLE 3 Comparison of the mean or median difference of each outcome among three intervention groups between pre- and post- 6 months after receiving CFOs ($n = 120$).

	Standard CFOs ($n = 40$)	CFOs with W1 ($n = 40$)	CFOs with W2 ($n = 40$)	*p* value	Effect size	*p* value (CFOs and W1)	*p* value (CFOs and W2)	*p* value (W1 & W2)
Worst pain, cm	−3.53 (2.33)	−2.71 (1.88)	−2.99 (3.08)	.243	0.317	-	-	-
Morning pain, cm	−2.5 [−4.7 to −1.1]	−2.1 [−3.3 to −1.0]	−2.3 [−5.5 to 0.9]	.856	0.104	-	-	-
Pain during gait, cm	−3.42 (1.95)	−3.13 (1.88)	−3.13 (2.68)	.650	0.174	-	-	-
Pain during standing, cm	−3.37 (2.02)	−2.73 (1.67)	−2.84 (2.91)	.443	0.241	-	-	-
Reaching distance, cm								
Symptomatic side	3.8 [−0.7 to 8.3]	6.3 [0.2 to 10.9]	5.5 [−2.5 to 10.1]	.916	0.077	-	-	-
Asymptomatic side	2.8 [−0.5 to 5.5]	4.6 [−3.0 to 11.2]	4.8 [−0.4 to 9.5]	.905	0.082	-	-	-
ECFS condition								
Length of minor axis, mm	−0.45 (1.76)	0.10 (1.65)	0.63 (1.84)	**.005***	2.522	.475	**.004‡**	.186
Length of major axis, mm	−1.15 (3.41)	−0.59 (2.19)	−0.10 (3.05)	.388	1.195	-	-	-
95% CEA, mm^2	−6.3 [−17.1 to 7.0]	−1.0 [−15.9 to 8.1]	−0.3 [−5.5 to 18.2]	**.006***	0.640	.089	**.002‡**	.083
CoP path length, mm	−12.9 [−32.5 to 7.3]	−10.8 [−40.1 to 8.2]	1.2 [−20.5 to 17.0]	.087	0.416	-	-	-
CoP velocity, mm/s	−0.48 (1.31)	−0.20 (1.61)	0.04 (1.65)	.382	1.195	-	-	-
ECSS condition								
Length of minor axis, mm	−2.62 (7.50)	−0.29 (10.59)	−0.56 (6.72)	.265	1.331	-	-	-
Length of major axis, mm	−5.25 (10.76)	0.13 (17.32)	0.00 (10.29)	.208	1.413	-	-	-
95% CEA, mm^2	−109.8 [−324.8 to 9.8]	−0.3 [−460.1 to 213.9]	7.5 [−113.4 to 117.0]	**.042***	0.491	**.020†**	.135	.160
CoP path length, mm	−92.3 [−217.6 to −3.1]	−88.4 [−207.0 to 45.9]	−60.5 [−122.9 to 62.5]	.204	0.339	-	-	-
CoP velocity, mm/s	−3.2 [−10.1 to 1.1]	−1.9 [−8.2 to 2.3]	−1.7 [−5.1 to 6.6]	.432	0.245	-	-	-
EOFS condition								
Length of minor axis, mm	0.2 [−0.9 to 1.4]	0.1 [−0.6 to 1.1]	0.8 [0.2 to 1.5]	**.008***	0.600	.169	**.004‡**	**.041**
Length of major axis, mm	1.10 (3.66)	−0.09 (2.57)	0.87 (3.01)	.347	1.219	-	-	-
95% CEA, mm^2	3.6 [−5.5 to 15.3]	1.6 [−9.0 to 11.6]	4.9 [−2.0 to 29.0]	**.037***	0.501	.175	**.012‡**	.177
CoP path length, mm	0.6 [−15.1 to 25.8]	−3.4 [−17.0 to 27.1]	6.7 [−27.1 to 25.3]	.536	0.209	-	-	-
CoP velocity, mm/s	0.4 [−0.6 to 1.3]	−0.2 [−0.7 to 1.4]	0.5 [−1.1 to 1.3]	.437	0.239	-	-	-
EOSS condition								
Length of minor axis, mm	−2.9 [−8.1 to 0.5]	1.4 [−4.4 to 3.9]	−0.1 [−4.4 to 4.8]	.077	0.429	-	-	-
Length of major axis, mm	−6.43 (9.95)	1.55 (11.63)	−0.16 (9.27)	.205	1.436	-	-	-
95% CEA, mm^2	−96.8 [−281.2 to 3.4]	69.9 [−186.0 to 142.0]	8.0 [−125.0 to 231.0]	**.015***	0.572	**.008†**	**.018‡**	.924
CoP path length, mm	−66.4 [−257.7 to 33.9]	−21.2 [−135.6 to 116.2]	−27.5 [−150.0 to 91.4]	**.013***	0.570	**.008†**	**.014‡**	.871
CoP velocity, mm/s	−2.8 [−10.7 to 1.7]	−0.2 [−5.7 to 5.9]	0.1 [−6.3 to 4.7]	.122	0.392	-	-	-

*Significant difference among groups.
†Significant difference between CFOs and W1.
‡Significant difference between CFOs and W2.
Abbreviations: CEA, confidence ellipse area; CFOs, custom foot orthoses; CoP, center of pressure; ECFS, eyes closed, firm surface; ECSS, eyes closed, soft surface; EOFS, eye open, firm surface; EOSS, eyes open, soft surface; W1, orthotic wedge type 1; W2, orthotic wedge type 2.

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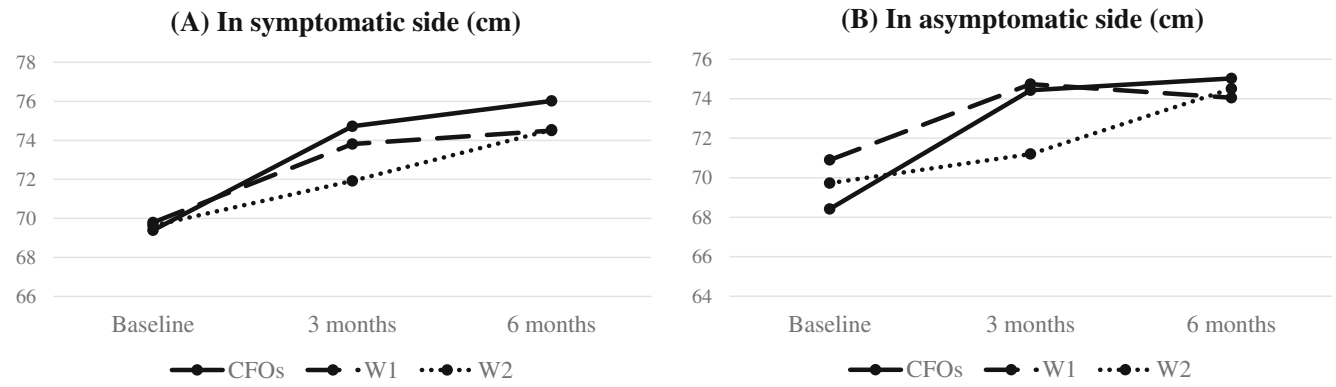


FIGURE 4 Between- and within-group comparison of reaching distance (cm): (A) In symptomatic side, (B) In asymptomatic side. CFOs, custom foot orthoses.

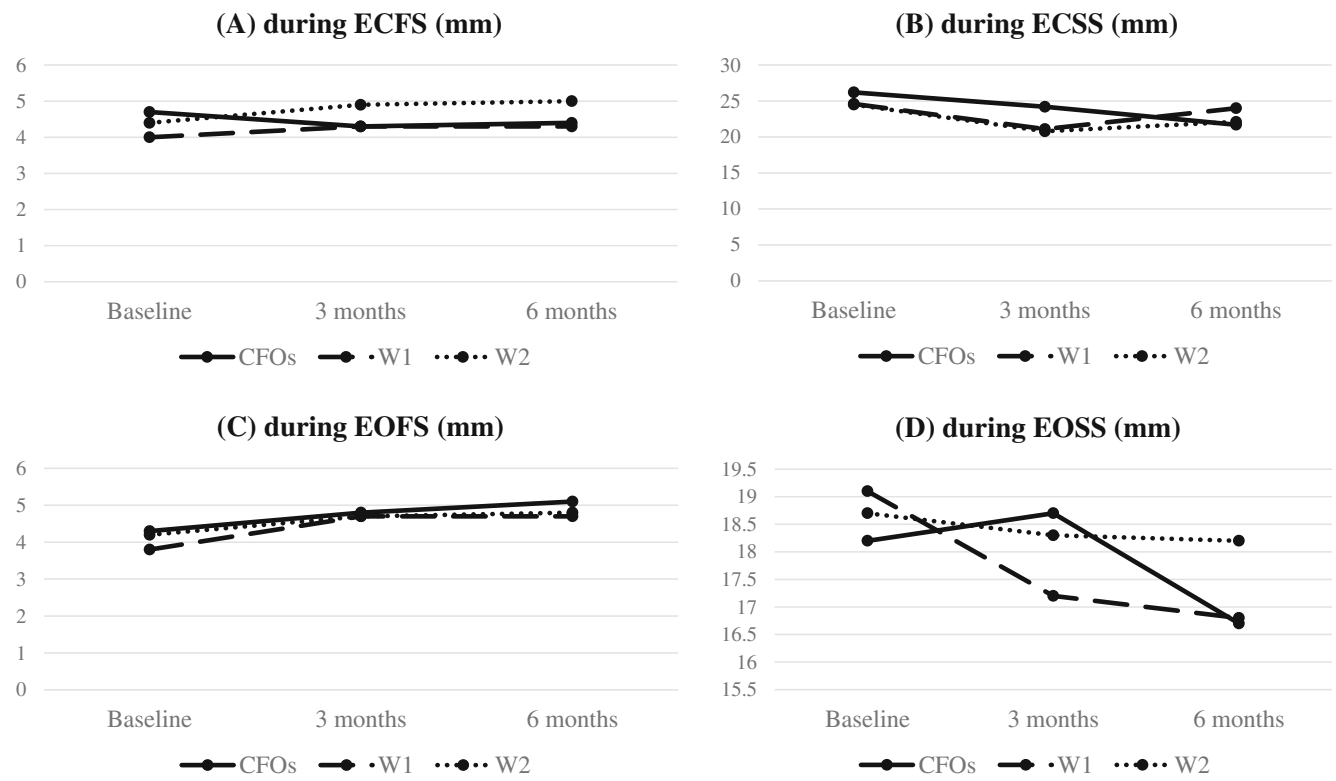


FIGURE 5 Between- and within-group comparison of the length of minor axis (mm): (A) during ECFS, (B) during ECSS, (C) during EOFS, (D) during EOSS. CFOs, custom foot orthoses; ECFS, eyes closed, firm surface; ECSS, eyes closed, soft surface; EOFS, eyes open, firm surface; EOSS, eyes open, soft surface.

which together facilitated more stable and efficient movement during dynamic tasks.[22,32]

Static balance parameters

The present study revealed significant differences in static balance parameters among the three intervention groups. The CFOs group demonstrated significantly improved balance parameters, particularly under the more challenging conditions (ECSS and EOSS), as evidenced by significant improvements in the medial-lateral and anterior-posterior sways, 95% CEA, CoP path length, and CoP velocity. These findings are consistent with Hammami et al., [22] who reported immediate improvements in postural balance with CFOs in middle-aged women with PF.

Notably, the CFOs without wedge group showed more consistent and broader improvements in static balance parameters, especially under eyes closed and/or soft surface conditions, compared to the CFOs with wedges (W1 and W2) groups. This suggests that the basic CFOs may provide better stability and

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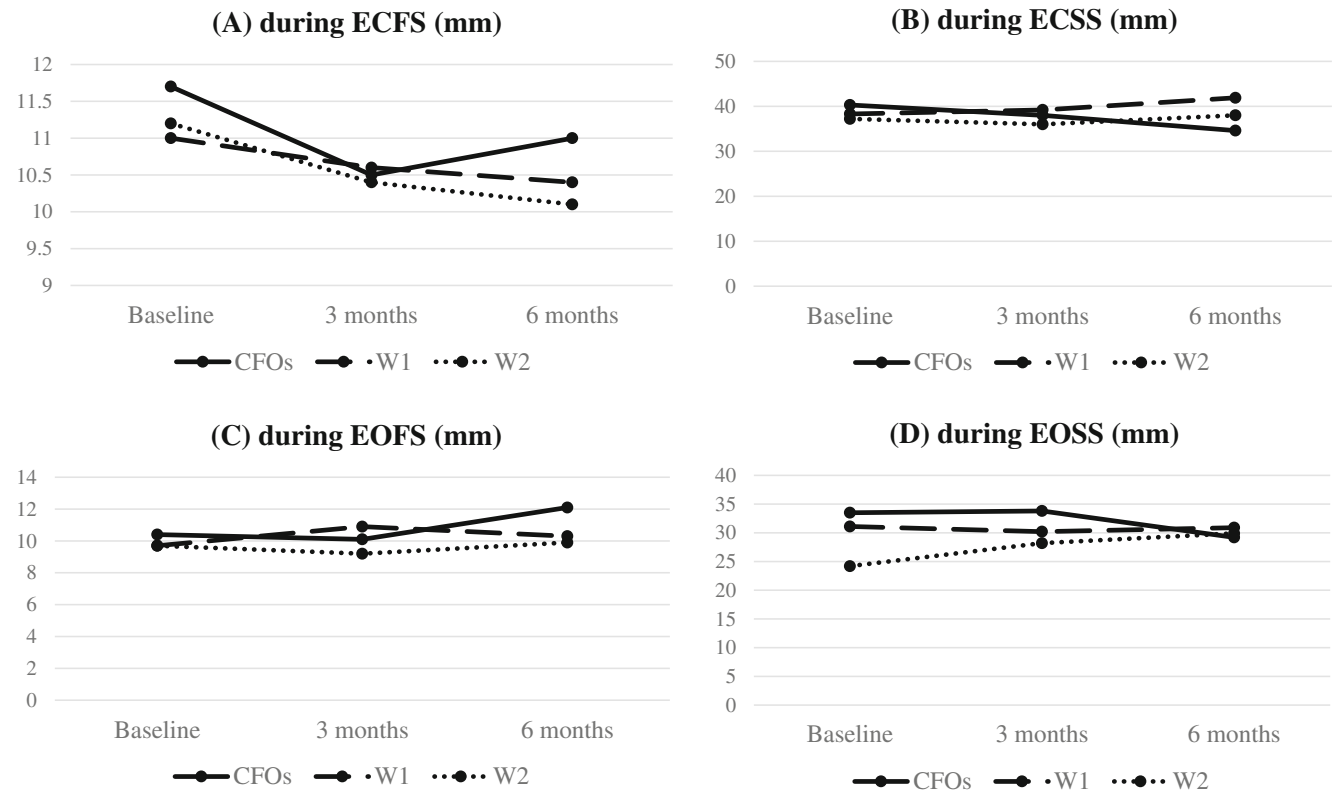


FIGURE 6 Between- and within-group comparison of the length of major axis (mm): (A) during ECFS, (B) during ECSS, (C) during EOFS, (D) during EOSS. CFOs, custom foot orthoses; ECFS, eyes closed, firm surface; ECSS, eyes closed, soft surface; EOFS, eyes open, firm surface; EOSS, eyes open, soft surface.

proprioceptive input for balance control in these scenarios. This finding is particularly interesting as it contradicts the common assumption that additional wedging would provide better balance outcomes. One possible explanation is the distribution of foot postures among groups: the CFOs group had a higher proportion of participants with supinated feet, which may be more responsive to orthotic intervention and symptom improvement than other foot types. Research indicates that foot posture can influence the biomechanical and proprioceptive effects of orthoses, with supinated feet potentially benefiting more from certain orthotic designs.[33,34]

The differences in static balance parameters between groups may be explained by the different biomechanical effects of the orthoses. Harutaichun et al.[23] demonstrated that different orthotic wedge designs produced different effects on lower limb kinematics during gait. The authors found that orthotic wedges with forefoot varus posting and a combination of forefoot and rearfoot varus posting could change lower limb kinematics and reduce the relative length of the plantar fascia, which may be associated with a reduction in pain and symptoms during walking.

Foot orthoses, especially custom designs, are widely used to address pain and functional deficits in PF, but their effects on static standing balance under different sensory conditions (firm/foam surfaces, eyes open/closed) are less well established. In a study of middle-aged women with obesity and PF, CFOs reduced postural sway and improved CoP area values during unipedal stance, compared to standard insoles and barefoot conditions.[22] However, this study did not specify the effects under different surface or visual conditions. Although direct studies in PF are limited, research in similar populations (eg, flatfoot) suggests that foot orthoses can improve static balance, particularly on challenging surfaces like foam and with eyes closed, by stimulating plantar mechanoreceptors and enhancing somatosensory input.[35] Therefore, foot orthoses could redistribute plantar pressures, support the arch, and may enhance proprioceptive feedback, which is especially beneficial in more challenging visual or surface conditions.[17,22,35]

Strengths, limitations and recommendations

Some limitations should be considered when interpreting the results of this study. First, the present study did not include a control group that received no intervention or a sham intervention, which would isolate the specific effects of the foot orthoses from potential placebo effects or the natural history of the condition. Second, the unequal distribution of foot postures among the

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intervention groups, particularly the higher proportion of participants with supinated feet in the CFOs group compared to the wedge groups may have confounded the observed effects of the orthoses on balance outcomes, making it difficult to attribute improvements solely to the orthotic intervention rather than to underlying differences in foot structure. Future studies should aim to match or control for foot posture across groups to more accurately assess the effects of orthosis design on balance. Finally, the predominance of female participants may limit the generalizability of the present findings to male patients. Although the distribution of gender was consistent across the three treatment arms, existing literature suggests that gender can influence the characteristics and prevalence of PF. For example, females generally have a higher incidence rate, whereas males with the condition tend to present with greater plantar fascia thickness.[36–38] Future research should, therefore, evaluate whether treatment outcomes differ between the genders. Despite these limitations, a major strength of the present study is the use of a randomized controlled trial design with intention-to-treat analysis, which maintains the integrity of randomization and minimizes bias. This methodological approach, combined with comprehensive assessment of both subjective pain outcomes and objective balance parameters over a 6-month period, provides robust evidence for the effectiveness of different CFOs designs in individuals with PF. Furthermore, this study is one of the few to directly compare different orthotic wedge designs based on distinct foot assessment techniques, offering valuable insights for clinical practice in the management of PF.

CONCLUSION

The present study demonstrated that CFOs with or without additional wedging are effective in reducing pain and improving balance in individuals with PF. The CFOs without wedge group showed more consistent improvements in balance parameters, particularly under challenging conditions, compared to the CFOs with wedges groups. These findings suggest that basic CFOs may be sufficient for managing PF, and additional wedging may not provide significant additional benefits. Future research should focus on identifying characteristics that may predict response to different types of foot orthoses, which would allow for more personalized and effective treatment approaches.

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DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT
The study protocol was approved by the Center of Ethical Reinforcement for Human Research of Mahidol University (COA no. MU-CIRB 2023/013.0102).

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DISCLOSURE
There was no conflict of interest to declare.

PATIENT CONSENT STATEMENT
This study used entirely anonymized images from which no individual could be identified. These images contain no identifying marks and are not accompanied by any text that might identify the individuals concerned. Consistent with the journal's guidelines for non-identifiable images, formal patient consent was not required for their use in this publication.

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