BMC Musculoskeletal Disorders

RESEARCH

Open Access

Effects of customized orthoses on foot morphology and pressure in patients with accessory navicular syndrome

Xiaopeng Pu[1†], Wenwen Xing[1†], Zishen Cheng[1], Yantao Wang[1], Yuqing Wang[1], Yaxing Zhang[1], Liangliang Jiang[1], Bin Liu[1] and Qiangjun Kang[1*]

Abstract

Objective This study aimed to assess the effects of customized orthoses on foot morphology and plantar pressure in professional athletes with accessory navicular syndrome (ANS) over a 12-month period, compared to conventional insoles.

Methods In this randomized controlled study, 54 pro athletes with medial foot pain, diagnosed with ANS, joined after 3-month training. Split into two groups: custom orthotics (intervention) or regular insoles (control). Evaluated at 3, 6, 12 months on foot structure (arch, navicular, etc.) and function (pressure, force-time integral, VAS pain). Found significant improvements in intervention group's foot shape, pressure distribution, and pain reduction compared to controls.

Results Compared to the control group, the intervention group showed significant increases in arch angle and arch height across all assessment intervals ($P < 0.05$). Additionally, heel eversion angle and navicular prominence distance significantly decreased in the intervention group compared to controls ($P < 0.05$). Pressure and force-time integral values at the first metatarsal head, medial arch, and medial heel significantly decreased, while lateral arch loading increased in the intervention group ($P < 0.05$). VAS scores for foot pain significantly decreased in the intervention group compared to controls ($P < 0.05$).

Conclusion Customized orthoses effectively improved foot morphology and reduced plantar pressure in professional athletes with ANS compared to conventional insoles. These findings suggest that customized orthotic intervention provides faster and more significant pain relief for patients with ANS-related medial arch collapse.

Trial registration Chinese Clinical Trial Registry (ChiCTR2500100238; Retrospectively registered on 04/07/2025).

Keywords Accessory navicular syndrome, Orthoses, Foot morphology, Plantar pressure, Professional athletes

[†]Xiaopeng Pu and Wenwen Xing contributed equally to this paper.

*Correspondence:
Qiangjun Kang
kankangqiangj123@126.com
[1]Third Department of Orthopedics, Bethune International Peace Hospital, Shijiazhuang, Hebei, China

Introduction

Accessory navicular syndrome (ANS) is a prevalent foot condition predominantly affecting the medial aspect of the foot where the accessory navicular bone is located [1, 2]. The accessory navicular is an abnormal development of the second ossification center of the navicular bone. The accessory navicular bone is not a normal bony structure, but the abnormal development of the ossification center of the peripheral bone tubercle, which forms an independent bone locally and protrudes from the skin surface [3, 4]. The primary symptoms of this syndrome include medial foot pain, particularly in the accessory navicular area, exacerbated by standing or walking, and may be accompanied by medial foot swelling and stiffness in the arch. The etiology of this syndrome can involve repetitive trauma, overuse, structural foot abnormalities (such as flatfoot), accessory navicular fractures or stress fractures, ligament injuries or degeneration, and posterior tibial nerve compression [5–7].

Diagnosis is typically based on a thorough medical history, physical examination, and imaging studies, such as X-rays, computerized tomography (CT) scans, or magnetic resonance imaging (MRIs) [8, 9]. Treatment options encompass conservative approaches (including rest, ice application, nonsteroidal anti-inflammatory drugs, appropriate footwear, arch supports, and physical therapy) and surgical interventions (considered when conservative measures fail) [3, 10, 11]. Early diagnosis and appropriate treatment are crucial for preventing symptom progression and improving outcomes.

Custom orthoses, designed based on individual plantar pressure data, are rehabilitation aids placed inside footwear to provide protection, support, and enhance activity levels [12–14]. These insoles have been widely used in rehabilitation and disease prevention fields [15, 16]. Custom orthoses serve as an effective conservative treatment for accessory navicular syndrome, offering several key benefits:

Personalized support Custom orthoses are tailored to the specific foot structure and issues of the patient, providing adequate arch support and reducing pressure on the accessory navicular area, thereby alleviating pain [13, 17].

Improved biomechanics By adjusting foot alignment and pressure distribution, custom insoles enhance biomechanical function and reduce abnormal stress on the accessory navicular region [16–18].

Non-invasive Compared to surgical interventions, custom orthoses offer a low-risk, highly accepted non-invasive treatment option [18].

Combination with other treatments Custom orthoses can be used alongside other conservative treatments (such as physical therapy, rest, and medication), enhancing overall treatment efficacy [19].

This study aims to evaluate the functional efficacy of custom orthoses by comparing foot morphology and pressure changes over a 12-month period between professional athletes with accessory navicular syndrome wearing customized corrective insoles and those wearing standard insoles.

Materials and methods

Study population

This study was conducted between July 2020 and August 2021, involving male athletes from a training base. From a total of 4311 athletes who underwent three months of formal training, 54 male athletes diagnosed with ANS were selected based on the presence of medial foot pain and confirmed accessory navicular on standard and oblique foot X-rays. The cohort included 13 individuals with Type I ANS and 41 with Type II or III ANS, of which 9 also had low arches. The subjects were randomly assigned into an observation group and a control group, each comprising 27 athletes. The observation group used customized orthoses, while the control group used standard insoles for ANS (Fig. 1A and B). The basic demographic information, including height, weight, age, and BMI, showed no significant differences between the two groups ($p > 0.05$) (Table 1). This study was approved by PLA 980th Hospital Medical Ethics Committee (No. 2024-KY-369). This study was conducted in accordance with the CONSORT guidelines for reporting clinical trials.

Diagnostic criteria

The diagnosis of ANS was based on clinical symptoms, physical examination, and imaging studies, referencing relevant literature. The diagnostic criteria included:

- Patient reports of medial foot pain localized at the navicular area, exacerbated by prolonged weight-bearing or activity.
- X-ray evidence of an accessory navicular. There were three types of the ANS [20]. Specifically, type I: round sesamoid bone can be seen on the X-ray film, and there is no connection with the navicular bone. Type II: The sesamoid is triangular, and there is a clear fibrous pseudojoint connection with the navicular bone. Type III: The sesamoid and ANS merge together to form the scaphoid horn of the foot.
- Physical examination findings of medial foot swelling, tenderness, or bony prominence.

Fig. 1 Images of Insoles and Measurement Equipment. **A**. Custom accessory navicular corrective insole **B**. Standard insole **C**. CORDEWENAR foot scanner **D**. Treadmill-based foot pressure testing system

Table 1 Basic information of participants

Parameter	Observation Group ($n=27$)	Control Group ($n=27$)	p-value
Age (years)	18.92 ± 1.56	19.75 ± 1.26	0.85
Height (cm)	174.67 ± 6.88	174.50 ± 4.87	0.25
Weight (kg)	64.32 ± 5.27	65.71 ± 3.70	0.06
BMI (kg/m^2)	18.67 ± 2.75	19.18 ± 1.78	0.25

Measurement equipment

- **Foot Morphology Scanner**: CORDEWENER Scaner 2.0 was used to measure the arch angle and medial prominence distance of the navicular.
- **Camera System**: CORDEWENER-Camera 2.5 was used to measure the medial arch height index and heel valgus angle.
- **Gait Analysis System**: CORDEWENAR foot scanner (Size: 66 × 44 × 11.5 cm, weight: 23 kg, scanning time: 8 s, carrying capacity: 180 kg.) was used for static data (Fig. 1C). Treadmill-based foot pressure testing system (Sensor area: 120 × 40 cm, slope 0–15%, size: 177 × 79 × 138 cm, sampling frequency: real-time frequency 200 Hz, speed: 0.8–18 km/h, maximum load bearing: 130 kg) was utilized for dynamic plantar pressure testing to assess gait parameters (Fig. 1D). The effectiveness and repeatability of Plantar data scanners have been demonstrated in previous studies [21].

The custom-made foot orthoses

Custom orthoses are usually modified and adjusted to the shoe block model through computer-aided design and manufacturing (CAD-CAM) after sufficient patient sole data has been collected. Then the repair data is uploaded to the mechanical milling machine to complete the engraving. The material used in the orthoses is ethylene-vinyl acetate copolymer with the molecular formula (C2H4)x.(C4H6O2)y. The orthotic device comprises a support panel, a columnar support structure and a non-slip bottom plate. The lower end of the support panel is arranged on the non-slip bottom plate, and the middle of one end of the support panel is provided with a columnar support structure. The support panel is composed of a front palm support plate, an auxiliary navicular bone support convex block and a heel cup wrapped block. The convex block is connected with the posterior calcaneus wrapping block.

Measured parameters

In this experiment, the foot data of all subjects were measured by asking them to take off their shoes and socks before measurement.

Foot morphology indicators

- **Arch Angle**: Measured using the scanner's angle measurement tool. The angle is formed between the line connecting the most prominent points on the first metatarsophalangeal joint and the heel (AB), and the line connecting the widest part of the arch to the apex (CO). A larger angle indicates a higher arch and a lower flatfoot index (Fig. 2A).

- **Medial Prominence Distance**: Measured using the scanner's distance measurement tool, representing the protrusion distance of the navicular (including the accessory navicular) from the medial aspect of the foot (D-D') (Fig. 2A).
- **Heel Valgus Angle**: Measured with the camera system's angle tool, representing the angle between the central line of the lower leg and the line connecting the medial and lateral malleoli and the heel midpoint (Fig. 2B).
- **Medial Arch Height**: Measured from the lower edge of the navicular to the ground using the camera system's height tool (B-B') (Fig. 2C).

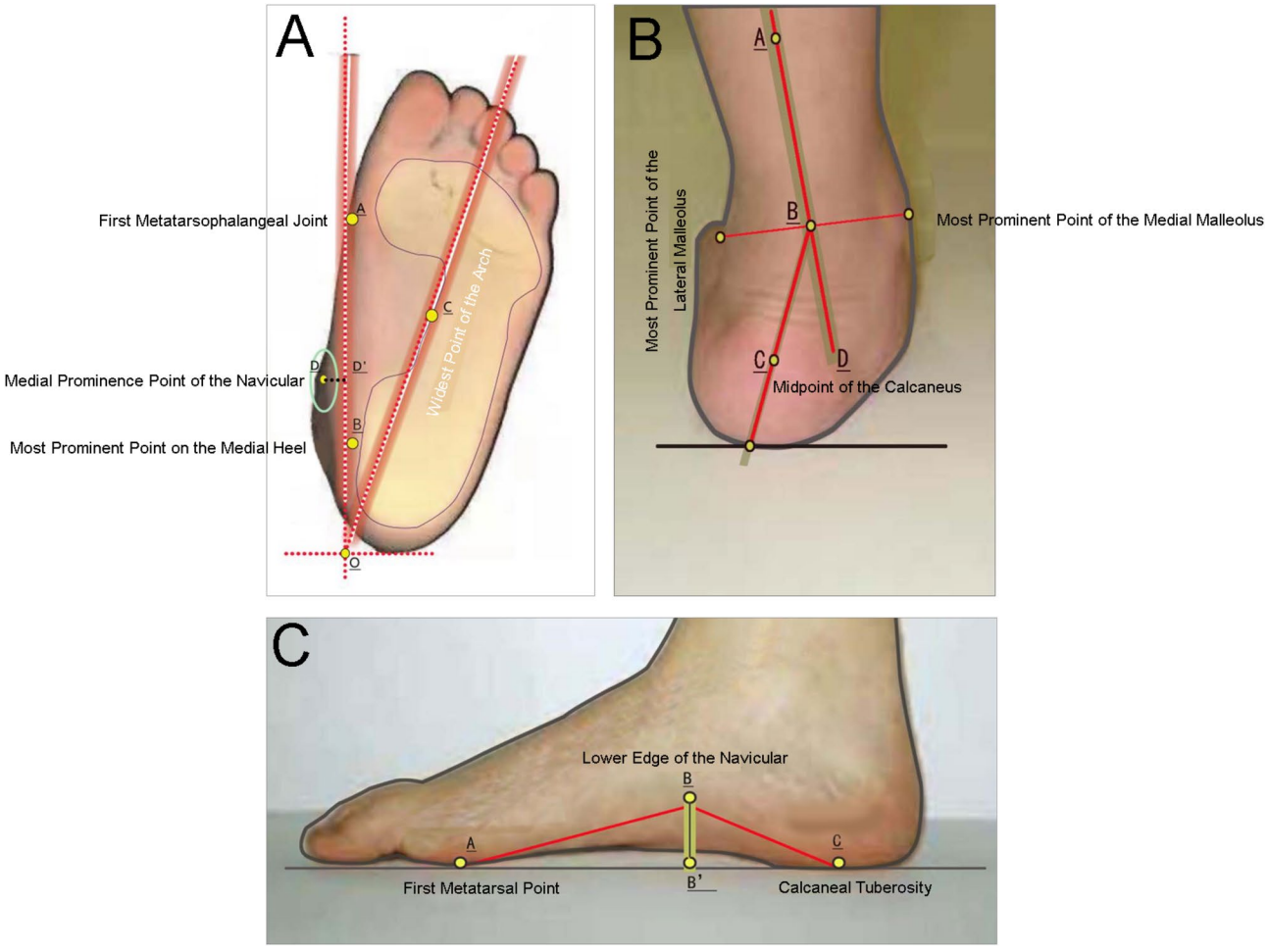

Fig. 2 Illustrations of Foot Measurements. **A**. Diagram illustrating the measurement of arch angle and navicular protrusion distance. **B**. Diagram illustrating the measurement of heel valgus angle. **C**. Diagram illustrating the measurement of medial arch height

Plantar pressure Indicators[22, 23]

- **Medial Arch Pressure**: Maximum plantar pressure of the medial arch (Fig. 3).
- **Medial Arch Impulse**: Maximum impulse of the medial arch.
- **Lateral Arch Pressure**: Maximum plantar pressure of the lateral arch.
- **Lateral Arch Impulse**: Maximum impulse of the lateral arch.
- **First Metatarsal Pressure**: Maximum pressure on the first metatarsal.
- **First Metatarsal Impulse**: Maximum impulse on the first metatarsal.
- **Heel Medial Pressure**: Maximum pressure on the medial heel.
- **Heel Medial Impulse**: Maximum impulse on the medial heel.
- **VAS Pain Score**: Visual Analog Scale (VAS) for pain assessment in both groups (Fig. 4).

Experimental methods

Grouping and insole allocation The selected ANS patients were divided into two groups (observation and control). The observation group received customized orthoses, while the control group received standard insoles (Figs. 2 and 3). Follow-up assessments were conducted at 3, 6, and 12 months. Data recorded included static foot morphology (arch angle, medial prominence distance, arch height, and heel valgus angle) and dynamic plantar pressure (maximum pressures and impulses at specified regions, and VAS pain scores).

Testing procedure Participants were informed about the testing procedures and asked to walk a few times to acclimate to the testing environment. VAS pain scores were recorded initially. Participants then walked naturally, barefoot, on the CORDEWENER-Gait Analys treadmill until complete dynamic foot data were captured for both feet.

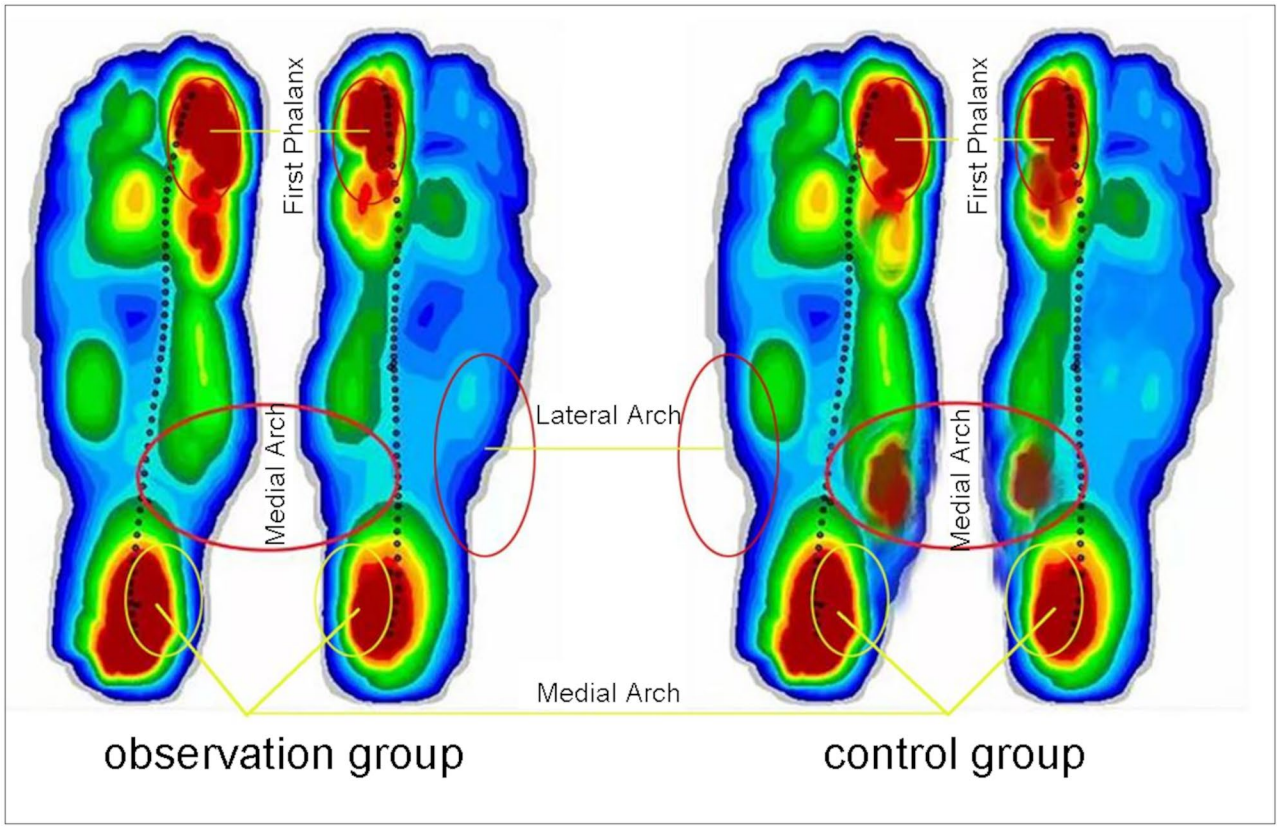

Fig. 3 Comparison of plantar pressure

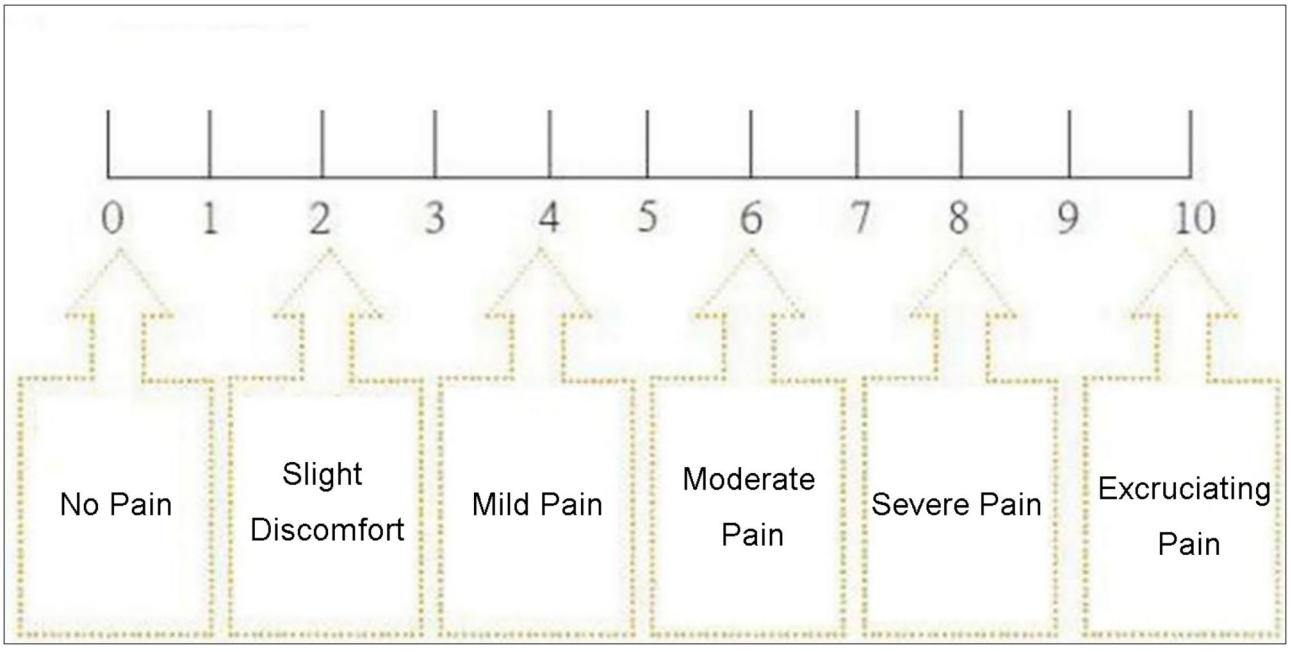

Fig. 4 VAS pain score scale for patients with accessory navicular syndrome

Table 2 Comparison of arch angles before and after adapting insoles (Unit: °)

Group	Before Adaptation	3 Months	6 Months	12 Months
Observation ($n=27$)	3.27 ± 1.26	8.69 ± 1.35*	13.64 ± 2.32*	15.45 ± 1.53*
Control ($n=27$)	3.73 ± 1.54	5.67 ± 0.82	6.49 ± 2.17	9.53 ± 1.68
t-test	0.932	4.265	5.379	4.658
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 3 Comparison of navicular bone protrusion distances before and after adapting insoles (Unit: mm)

Group	Before Adaptation	3 Months	6 Months	12 Months
Observation ($n=27$)	6.37 ± 1.25	4.72 ± 1.63*	2.62 ± 0.85*	1.78 ± 0.41*
Control ($n=27$)	6.69 ± 1.27	5.33 ± 0.85	3.52 ± 1.164	3.53 ± 0.77
t-test	0.654	3.578	3.627	4.535
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 4 Comparison of arch heights before and after adapting insoles (Unit: mm)

Group	Before Adaptation	3 Months	6 Months	12 Months
Observation ($n=27$)	9.64 ± 1.42	12.79 ± 2.38*	14.62 ± 1.85*	16.47 ± 2.71*
Control ($n=27$)	10.31 ± 1.57	12.24 ± 1.79	12.53 ± 1.68	13.54 ± 2.76
t-test	0.863	3.175	3.458	4.217
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Static data measurement procedure Before the test, the subject was informed of the test procedure, the soles are cleaned with wet wipes, and the subject stand naked on the CORDEWENER-Gait Analysis System foot scanner with the front of the foot facing in front of the instrumentation, remaining standing for more than 15 s. (CORDEWENER-Gait Analysis system plantar scanner: size: 66 × 44 × 11.5 cm (L x W x H), scanning time: 8 s, carrying capacity: 180 kg).

Dynamic data measurement procedure Before the test, the subject was informed to walk several times to adapt to the test environment until met the test requirements. The person usually walks with the left and right feet alternating naturally, and walks several times back and forth on the CORDEWENER-Gait Analys system running platform until the computer shows that the complete foot dynamic information of the two feet has been collected. The dynamic data of the subject's foot can be obtained after the manipulation. (CORDEWENER-Gait Analysis system: sensor area: 120 × 40 cm, slope 0–15%, size: 177 × 79 × 138 cm, sampling frequency: real-time frequency 200 Hz, speed: 0.8–18 km/h, maximum load bearing: 130 kg).

Statistical analysis

Data were analyzed using SPSS 20.0 software. Means were expressed as mean ± sd. All the data in this experiment were in line with normal distribution, and T-test was used between the two groups of data for analysis by professional statistical experts, with a significance level set at $p < 0.05$.

Results

Comparison of arch angles

Professional corrective insoles for accessory navicular led to significantly larger arch angle improvements at 3, 6, 12 months versus regular insoles ($P < 0.05$). Observation group angles changed to 8.69 ± 1.35°, 13.64 ± 2.32°, 15.45 ± 1.53° respective to time points (Table 2).

Comparison of navicular bone protrusion distances

Observation group noted significantly larger decreases in navicular protrusion distances at 3, 6, 12 months post-intervention vs. control ($P < 0.05$). Distances reduced to 4.72 ± 1.63 mm, 2.62 ± 0.85 mm, 1.78 ± 0.41 mm at respective intervals (Table 3).

Comparison of arch heights

Observation group saw significantly larger arch height rises at 3, 6, 12 months vs. control ($P < 0.05$). Heights rose to 12.79 ± 2.38 mm, 14.62 ± 1.85 mm, 16.47 ± 2.71 mm at each milestone (Table 4).

Comparison of heel Valgus angles

Observation group achieved faster, significant heel valgus angle correction at 3, 6, 12 months vs. control ($P < 0.05$). Angles fell to 13.57 ± 2.25°, 10.42 ± 2.89°, 7.93 ± 3.17° over time (Table 5).

Table 5 Comparison of heel Valgus angles before and after adapting insoles (Unit: °)

Group	Before Adaptation	3 Months	6 Months	12 Months
Observation ($n=27$)	18.21 ± 3.17	13.57 ± 2.25*	10.42 ± 2.89*	7.93 ± 3.17*
Control ($n=27$)	18.93 ± 2.28	14.62 ± 2.67	13.58 ± 3.24	11.55 ± 2.67
t-test	0.635	3.577	4.634	4.791
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 6 Comparison of maximum medial arch pressure before and after adapting insoles (Unit: N)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	235.66 ± 12.59	197.9 ± 1.62*	149.58 ± 3.99*	57.62 ± 2.95*
Control ($n=27$)	231.73 ± 11.66	218.59 ± 1.27	188.35 ± 3.26	175.63 ± 2.38
t-test	0.545	4.354	5.399	4.828
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	237.92 ± 13.26	201.76 ± 2.91*	157.58 ± 3.29*	63.47 ± 1.88*
Control ($n=27$)	236.72 ± 2.47	209.65 ± 1.73	179.46 ± 3.28	168.33 ± 2.59
t-test	0.694	4.553	5.135	4.277
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 7 Comparison of maximum medial arch impulse before and after adapting insoles (Unit: N·s)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	26.65 ± 0.88	34.23 ± 0.77*	48.67 ± 1.32*	63.74 ± 1.59*
Control ($n=27$)	27.54 ± 0.26*	32.69 ± 1.75	36.77 ± 0.53	38.28 ± 3.11
t-test	0.685	3.417	3.583	4.229
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	26.32 ± 0.74	33.39 ± 0.62	45.33 ± 1.58*	62.48 ± 1.37*
Control ($n=27$)	28.64 ± 0.35	33.49 ± 1.28	36.24 ± 0.71	38.57 ± 1.32
t-test	0.677	3.251	3.732	4.645
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Comparison of maximum medial arch pressure

Professional corrective insoles significantly reduced max medial arch pressure in both left/right feet at 3, 6, 12 months vs. control ($P<0.05$). Left: 197.9 ± 1.62 N, 149.58 ± 3.99 N, 57.62 ± 2.95 N; Right: 201.76 ± 2.91 N, 157.58 ± 3.29 N, 63.47 ± 1.88 N at respective intervals (Table 6).

Comparison of maximum medial arch impulse

Professional corrective insoles significantly raised max medial arch impulse in both feet at 3, 6, 12 months vs. control ($P<0.05$). Left: 34.23 ± 0.77 N•s, 48.67 ± 1.32 N•s, 63.74 ± 1.59 N•s; Right: 33.39 ± 0.62 N•s, 45.33 ± 1.58 N•s, 62.48 ± 1.37 N•s at respective times (Table 7).

Comparison of maximum lateral arch pressure

Corrective insoles led to significant max lateral arch pressure changes vs. control at 3, 6, 12 months ($P<0.05$). Left: 71.45 ± 3.22 N to 118.27 ± 12.14 N; Right: 75.56 ± 3.19 N to 117.43 ± 11.65 N over time (Table 8).

Comparison of maximum lateral arch impulse

Corrective insoles induced significant max lateral arch impulse alterations vs. control at 3, 6, 12 months ($P<0.05$). Left: 43.67 ± 1.59 N•s to 18.74 ± 1.59 N•s; Right: 33.39 ± 0.62 N•s to 16.62 ± 1.26 N•s over the period (Table 9).

Comparison of maximum pressure on the first phalanx

Corrective insoles yielded significant max pressure reductions on the first metatarsal vs. control at 3, 6, 12 months ($P<0.05$). Left: 46.25 ± 0.74 N to 27.62 ± 2.95 N; Right: 41.76 ± 3.58 N to 21.55 ± 1.74 N over the timeline (Table 10).

Table 8 Comparison of maximum lateral arch pressure before and after adapting insoles (Unit: N)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	67.23 ± 2.17	71.45 ± 3.22	89.46 ± 1.28	118.27 ± 12.14*
Control ($n=27$)	92.44 ± 2.19	98.35 ± 2.17	104.59 ± 1.24	111.36 ± 11.52
t-test	0.531	4.296	4.375	4.817
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	62.29 ± 1.53	75.56 ± 3.19	92.28 ± 2.93	117.43 ± 11.65*
Control ($n=27$)	98.32 ± 1.64	99.46 ± 1.68	109.53 ± 1.08	126.32 ± 2.15
t-test	0.594	4.635	5.288	4.176
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 9 Comparison of maximum lateral arch impulse before and after adapting insoles (Unit: N·s)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	47.62 ± 0.38	43.67 ± 1.59	34.25 ± 0.76	18.74 ± 1.59*
Control ($n=27$)	32.54 ± 0.26	29.57 ± 1.23	28.62 ± 0.49	25.28 ± 3.11
t-test	0.632	3.427	3.516	4.219
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	44.37 ± 0.81	33.39 ± 0.62	25.33 ± 1.58	16.62 ± 1.26*
Control ($n=27$)	31.29 ± 0.72	26.24 ± 0.21	23.32 ± 1.13	17.51 ± 1.04
t-test	0.579	3.141	3.432	4.585
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 10 Comparison of maximum pressure on the first phalanx before and after adapting insoles (Unit: N)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	55.66 ± 10.43	46.25 ± 0.74	31.46 ± 2.91	27.62 ± 2.95*
Control ($n=27$)	51.63 ± 12.75	48.28 ± 1.37	44.36 ± 2.53	42.32 ± 2.17
t-test	0.545	4.354	5.399	4.828
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	57.91 ± 8.23	41.76 ± 3.58	27.52 ± 2.79	21.55 ± 1.74*
Control ($n=27$)	61.45 ± 3.69	58.65 ± 1.14	54.46 ± 3.21	51.34 ± 3.11
t-test	0.694	4.553	5.135	4.277
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Comparison of maximum impulse on the first phalanx

Corrective insoles led to substantial max impulse increments on the first metatarsal vs. control at 3, 6, 12 months ($P<0.05$). Left: 44.21 ± 0.64 N•s to 58.62 ± 1.32 N•s; Right: 37.39 ± 0.17 N•s to 56.34 ± 0.28 N•s over the course (Table 11).

Comparison of maximum medial heel pressure

Corrective insoles triggered significant decreases in max medial heel pressure vs. control at 3, 6, 12 months ($P<0.05$). Left: 297.39 ± 2.62 N to 253.71 ± 2.32 N; Right: 361.37 ± 2.28 N to 241.25 ± 1.38 N over time (Table 12).

Comparison of maximum medial heel impulse

Corrective insoles marked higher max medial heel impulse reductions vs. control at 3, 6, 12 months ($P<0.05$). Left: 67.26 ± 0.59 N•s to 107.54 ± 0.37 N•s; Right: 53.39 ± 0.62 N•s to 105.78 ± 1.24 N•s over the span (Table 13).

Pain relief effect comparison

Corrective insoles significantly outperformed standard insoles in reducing VAS pain scores after 12 months ($P<0.05$). Left foot pain scores: observation 1.54 ± 0.71 vs. control 4.38 ± 0.57; Right foot: 1.76 ± 0.21 vs. 4.19 ± 0.73 (Table 14).

Table 11 Comparison of maximum impulse on the first phalanx before and after adapting insoles (Unit: N·s)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	27.13 ± 0.23	44.21 ± 0.64*	53.15 ± 1.29*	58.62 ± 1.32*
Control ($n=27$)	25.16 ± 3.21	28.69 ± 1.41	33.72 ± 0.15	37.54 ± 0.26
t-test	0.574	3.431	4.358	4.725
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	22.43 ± 1.61	37.39 ± 0.17*	49.33 ± 1.35*	56.34 ± 0.28*
Control ($n=27$)	19.36 ± 1.07	21.29 ± 1.08	23.24 ± 0.52	28.25 ± 0.13
t-test	0.535	4.221	3.852	4.749
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 12 Comparison of maximum medial heel pressure before and after adapting insoles (Unit: N)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	384.29 ± 1.65	297.39 ± 2.62*	249.32 ± 3.17*	253.71 ± 2.32*
Control ($n=27$)	380.26 ± 1.59	377.25 ± 1.58	358.35 ± 1.59	346.37 ± 2.19
t-test	0.543	4.206	5.279	4.035
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	382.66 ± 1.59	361.37 ± 2.28*	257.58 ± 1.04*	241.25 ± 1.38*
Control ($n=27$)	388.92 ± 2.25	379.45 ± 1.09	364.25 ± 1.54	335.67 ± 2.41
t-test	0.574	4.539	4.677	4.358
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, indicating significant difference compared to the control group

Table 13 Comparison of maximum medial heel impulse before and after adapting insoles (Unit: N·s)

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	43.77 ± 0.23	67.26 ± 0.59***	88.67 ± 1.09***	107.54 ± 0.37****
Control ($n=27$)	38.29 ± 0.46	48.69 ± 1.07*	55.77 ± 0.24*	65.16 ± 1.03
t-test	0.654	3.231	3.579	4.585
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	41.68 ± 0.22	53.39 ± 0.62***	45.33 ± 1.58**	105.78 ± 1.24****
Control ($n=27$)	40.42 ± 0.51	52.27 ± 1.19*	58.36 ± 0.48*	61.74 ± 1.39
t-test	0.612	3.021	3.453	4.562
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, **$P<0.01$, ***$P<0.001$, indicating significant difference compared to the control group

Table 14 Comparison of VAS pain scores before and after insole adaptation

Group	Before Adaptation	3 Months	6 Months	12 Months
Left Foot				
Observation ($n=27$)	8.55 ± 1.34	4.32 ± 0.15*	3.21 ± 1.03	1.54 ± 0.71***
Control ($n=27$)	8.49 ± 1.27	6.25 ± 0.11	5.39 ± 0.46	4.38 ± 0.57*
t-test	0.459	3.575	3.843	4.226
P-value	>0.05	<0.05	<0.05	<0.05
Right Foot				
Observation ($n=27$)	8.32 ± 1.06	4.89 ± 0.27*	2.84 ± 1.17	1.76 ± 0.21***
Control ($n=27$)	8.87 ± 1.14	6.33 ± 0.35	5.66 ± 0.28	4.19 ± 0.73
t-test	0.284	3.673	3.549	4.532
P-value	>0.05	<0.05	<0.05	<0.05

Note: *$P<0.05$, **$P<0.01$, ***$P<0.001$, indicating significant difference compared to the control group

Discussion

The bone structure of the foot of young athletes have been fully developed and mature, and it is difficult to change it in a short time due to external stress. (1) Adult foot scaphoid deformity is a permanent deformity caused by bone growth. After adult bone stops growing and developing, it is impossible to change its bone structure by wearing CM-FOD for a short period of time. (2) Although CM-FOD could not change the bone deformity, it can significantly improve the soft tissue or biomechanical balance of the foot. Through the data analysis of the sole data of young athletes wearing professional foot orthopedic insoles for a short period of time (1 month), we know that the static data of the sole, including [1] the angle of the arch [2], the distance of scaphoid scoliosis [3], on significant differences the in height of the arch and the Angle of the heel varus. However, when wearing professional orthopedic insole for a long time (more than 3 months), it is found that there were significant differences in bone structure through foot test data, so it is necessary to adhere to wearing professional orthopedic insole regularly.

Custom orthoses, designed to fit individual patient needs, are inserted into shoes to provide protection, support, and enhanced mobility. They have been widely used in rehabilitation and disease prevention [24–27]. Custom orthoses are typically designed using data collected from foot pressure plates and foot scanners, which provide information on static and dynamic foot pressure, foot contours, and arch indices. This data is then used in computer-aided design and manufacturing (CAD-CAM) to create and adjust the insole model. This process is more personalized and scientifically rigorous compared to prefabricated and semi-prefabricated insoles. As research into foot and ankle biomechanics and overall lower limb mechanics continues, the application of orthoses has become more widespread. However, there is a lack of literature, both domestically and internationally, on the use of custom orthoses for treating accessory navicular syndrome. Issever reported good results after having a child with accessory navicular syndrome wear shoes with orthoses, avoiding intense foot stimulation for seven months [28]. A case report tracking the outcomes of surgical and conservative orthotic treatments in two patients with accessory navicular syndrome found that orthotic treatment significantly relieved pain and restored similar activity levels to surgical treatment [29]. Although clinical trials and reviews on orthotic insole treatment for accessory navicular syndrome are limited, the mechanism of orthoses suggests they can be used as a conventional conservative treatment for this condition.

Foot pain caused by accessory navicular can be attributed to three main factors: [1] localized irritation from training shoes on the medial accessory navicular prominence [2], structural variation of the posterior tibial tendon caused by the presence of the accessory navicular, leading to increased tension and tendinopathy, and [3] osseous pain from bone marrow edema due to chronic friction and strain at the accessory navicular-navicular joint interface [5, 9, 30, 31]. To address these pain mechanisms, we designed a supportive corrective insole specifically for accessory navicular, which has been patented. The insole includes a support panel, columnar support structure, and non-slip bottom plate. The support panel, located at the bottom of the non-slip plate, features a columnar support structure in the middle and consists of a forefoot support plate, accessory navicular support protrusion, and heel cup wrap block (see Fig. 1A). This customized orthotic insole effectively prevents accessory navicular protrusion, alleviating localized irritation from training shoes. The long-term action of the medial columnar support structure can further elevate the arch, reduce tension in the posterior tibial tendon, and improve local blood circulation and inflammatory conditions, significantly alleviating tendinous pain. The heel cup wrap block stabilizes the heel, reducing micro-movement caused by posterior tibial tendon tension, thereby relieving osseous pain from bone marrow edema.

We evaluated the effectiveness of the corrective insoles for accessory navicular using the following foot morphology and plantar pressure indicators:

1) **Arch Angle**: The arch angle reflects the contact area of the foot with the ground and is an important indicator of accessory navicular-related flatfoot. The normal range is 6–15° [32, 33]. A larger arch angle indicates a higher arch. In our study, patients in the observation group using customized accessory navicular corrective insoles showed a greater increase in arch angle compared to those using standard insoles, indicating effective correction. The observation group reached a reasonable angle within three months, demonstrating faster correction compared to the control group.
2) **Navicular Protrusion Distance**: This measures the horizontal protrusion distance of the navicular bone towards the medial side of the foot, a characteristic of accessory navicular-related flatfoot. The observation group showed a significant reduction in navicular protrusion distance over time, indicating improved navicular height and reduced accessory navicular protrusion. The correction speed was faster, and the correction duration shorter with customized insoles compared to standard insoles.
3) **Arch Height**: A traditional indicator of arch index, arch height is typically lower in patients with accessory navicular-related flatfoot [34]. The observation group using customized insoles showed

better and faster recovery of medial arch height compared to the control group, demonstrating significant improvement in accessory navicular-related arch height.

4) **Heel Valgus Angle**: This commonly used index measures the valgus angle of the heel, which is an important indicator of accessory navicular-related flatfoot. The normal range is 6–12° [35]. Angles exceeding 12° indicate flatfoot. The observation group reached a reasonable angle within six months, while the control group took twelve months.
5) **Maximum Plantar Pressure**: This biomechanical indicator reflects the load on the medial arch, crucial for assessing accessory navicular-related flatfoot. Lower pressure values indicate less severity and symptom relief. The observation group showed significant reductions in maximum pressure at the first metatarsal, medial arch, and medial heel, with increased pressure on the lateral arch, indicating effective correction.
6) **Maximum Plantar Pressure Impulse**: Reflecting the pressure relief process, this metric is the product of force and time. It indicates local foot impact forces. The observation group showed increased impulses at the first metatarsal, medial arch, and medial heel, indicating reduced ground impact speed and pain. The lateral arch impulse decreased, suggesting restored lateral arch load and foot balance. The customized insoles corrected faster and more effectively than standard insoles.
7) **VAS Pain Score**: The VAS (visual analog scale) is commonly used to assess pain, offering simplicity, cost-effectiveness, and quick evaluation [36, 37]. However, it can be imprecise for specific pain locations. This study used a customized VAS scale for accessory navicular pain, with specialized scoring different from general VAS scales. The observation group showed better pain relief and faster recovery compared to the control group, demonstrating significant improvement in arch-related pain.

In summary, customized accessory navicular corrective insoles provide superior overall correction and pain relief compared to standard insoles. However, limitations include the lack of fully customized design based on individual foot shapes and insufficient targeting of different accessory navicular subtypes. Future research should focus on optimizing orthotic insole design for personalized fitting, differentiating designs for various accessory navicular subtypes, and conducting large-scale, multicenter clinical studies to verify long-term efficacy and safety, promoting clinical application. The sample size of this study was determined based on the sample size of previous similar studies [38]. Therefore, the minimum sample size was not calculated separately in this study. In the future, the functional benefits of wearing CM-FOD for a longer period of time (such as 3–5 years) in a large sample size need to be further followed up, which is the limitation of this study.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-025-08689-7.

Supplementary Material 1

Acknowledgements
None.

Author contributions
QK and XP contributed to the conception and design of the study. WX, ZC and YW contributed to the acquisition of data. YZ and YW contributed to the analysis of data. XP wrote the manuscript. LJ and BL supervised the revision of the manuscript. QK worte the final manuscript. All authors approved the final version of the manuscript.

Funding
No funding was received for this study.

Data availability
Data is provided within the manuscript files.

Declarations

Ethics approval and consent to participate
The study protocol was approved by the Ethics Committee of Bethune International Peace Hospital, and the study was performed in accordance with the Helsinki II declaration. Informed consent was obtained from all the study subjects before enrollment.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Clinical trial number
Not applicable.

Received: 23 July 2024 / Accepted: 23 April 2025
Published online: 17 May 2025

References

1. Rammelt S, Sands AK. The accessory navicular and its association with Flatfoot. Fuß Sprunggelenk. 2020;18(1):60–71.
2. Campbell JT, Jeng CL. Painful accessory navicular and spring ligament injuries in athletes. Clin Sports Med. 2020;39(4):859–76.
3. Kopp FJ, Marcus RE. Clinical outcome of surgical treatment of the symptomatic accessory navicular. Foot Ankle Int. 2004;25(1):27–30.
4. Tian F, Wang J, Liu C, Li Y, Liang X, Wang X. Medial column reinforcement for the correction of Flatfoot deformity with accessory navicular bone. Am J Translational Res. 2022;14(9):6368.
5. Lawson J, Ogden J, Sella E, Barwick K. The painful accessory navicular. Skeletal Radiol. 1984;12:250–62.
6. Jegal H, Park YU, Kim JS, Choo HS, Seo YU, Lee KT. Accessory navicular syndrome in athlete vs general population. Foot Ankle Int. 2016;37(8):862–7.
7. Park H, Hwang JH, Seo JO, Kim HW. The relationship between accessory navicular and flat foot: a radiologic study. J Pediatr Orthop. 2015;35(7):739–45.

8. Waguespack R, Hanson RR. Navicular syndrome in equine patients anatomy, causes, and diagnosis. Compend Contin Educ Vet. 2010;32(12):E7.
9. Pothiawala S. Os Navicular Syndrome: A Symptomatic Accessory Ossicle of the Foot. Case Reports in Clinical Practice. 2022.
10. Kumahashi N, Kuwata S, Imade S, Uchio Y. Osteomyelitis of the accessory and body of the navicular bone: a case report. J Pediatr Orthop B. 2017;26(6):515–8.
11. Wynn M, Brady C, Cola K, Rice-Denning J. Effectiveness of nonoperative treatment of the symptomatic accessory navicular in pediatric patients. Iowa Orthop J. 2019;39(1):45.
12. Bonanno DR, Ledchumanasarma K, Landorf KB, Munteanu SE, Murley GS, Menz HB. Effects of a contoured foot orthosis and flat insole on plantar pressure and tibial acceleration while walking in defence boots. Sci Rep. 2019;9(1):1688.
13. Shunxun L, Yichun S, Jin Z, Bo X, Zhifeng Y, Wei L, INVESTIGATION OF THE EFFECTIVENESS OF PLANTAR PRESSURE REDISTRIBUTION OF CUSTOMIZED INSOLE STRUCTURE DESIGNED BASED ON PLANTAR STRUCTURE, Leather. & Footwear Journal/Revista De Pielarie Incaltaminte. 2023;23(2).
14. Mandolini M, Brunzini A, Germani M. A collaborative web-based platform for the prescription of Custom-Made insoles. Adv Eng Inform. 2017;33:360–73.
15. Tse CT, Ryan MB, Dien J, Scott A, Hunt MA. An exploration of changes in plantar pressure distributions during walking with standalone and supported lateral wedge insole designs. J Foot Ankle Res. 2021;14:1–11.
16. Tang Y, Cheng S, Zou L, Zhou L, Liang P, Ren H, et al. Effects of custom-made orthotic insoles on lower limb biomechanics in children with flexible flat feet. Revista De Pielărie Încălțăminte. 2023;23:2.
17. Khorasani SGR, Cham MB, Sharifnezhad A, Saeedi H, Farahmand B. Comparison of the immediate effects of prefabricated soft medical insoles and custom-molded rigid medical insoles on plantar pressure distribution in athletes with flexible Flatfoot: a prospective study. Curr Orthop Pract. 2021;32(6):578–83.
18. Albert S, Rinoie C. Effect of custom orthotics on plantar pressure distribution in the pronated diabetic foot. J Foot Ankle Surgery: Official Publication Am Coll Foot Ankle Surg. 1994;33(6):598–604.
19. Payak H. Physiotherapy in musculoskeletal conditions: AB 115: A pilot study on the effect of custom made orthotic insoles on plantar peak pressure in athletes. J Soc Indian Physiotherapists. 2022;6(2):66.
20. Alsager GA, Alzahrani K, Alshayhan F, Alotaibi RA, Murrad K, Arafah O. Prevalence and classification of accessory navicular bone: a medical record review. Ann Saudi Med. 2022;42(5):327–33.
21. Jasiewicz B, Klimiec E, Młotek M, Guzdek P, Duda S, Adamczyk J, et al. Quantitative analysis of foot plantar pressure during walking. Med Sci Monitor: Int Med J Experimental Clin Res. 2019;25:4916–22.
22. Buldt AK, Allan JJ, Landorf KB, Menz HB. The relationship between foot posture and plantar pressure during walking in adults: A systematic review. Gait Posture. 2018;62:56–67.
23. Tsujinaka S, Shima H. Comparison of plantar pressure distribution between postoperative hallux Valgus feet and healthy feet. Foot Ankle Int. 2019;40(5):578–85.
24. Khodaei B, Saeedi H, Farzadi M, Norouzi E. Comparison of plantar pressure distribution in CAD–CAM and prefabricated foot orthoses in patients with flexible flatfeet. Foot. 2017;33:76–80.
25. Tedeschi R, Labanca L, Platano D, Benedetti MG. A Decision-Making tool for prescribing insoles in daily practice using an insole prescription form. JPO: J Prosthetics Orthot. 2024;36(3):e60–6.
26. Singh S, Mali HS. 3D printed orthotic insoles for foot rehabilitation. 3D printing in podiatric medicine. Elsevier; 2023. pp. 211–9.
27. Guiotto A, Santini D, Bertoncello E, Sawacha Z. Gait analysis driven design and 3D printing of plantar foot orthosis. Gait Posture. 2022;97:35.
28. Issever AS, Minden K, Eshed I, Hermann K-GA. Accessory navicular bone: when ankle pain does not originate from the ankle. Clin Rheumatol. 2007;26:2143–4.
29. Smith TR. Management of dancers with symptomatic accessory navicular: 2 case reports. J Orthop Sports Phys Therapy. 2012;42(5):465–73.
30. Xiang F, Liu Z-Q, Zhang X-P, Li Y-J, Wen J. Accessory navicular in children. World J Clin Cases. 2023;11(35):8256.
31. Iyengar KP, Sharma GK, Botchu R. Accessory tibionavicular muscle: an unusual cause of medial ankle pain. Indian J Radiol Imaging. 2023;32.
32. Khan F, Chevidikunnan MF, Alsobhi MG, Ahmed IAI, Al-Lehidan NS, Rehan M, et al. Diagnostic accuracy of various radiological measurements in the evaluation and differentiation of Flatfoot: A Cross-Sectional study. Diagnostics. 2022;12(10):2288.
33. Alsaidi FA, Moria KM. Flatfeet Severity-Level detection based on alignment measuring. Sensors. 2023;23(19):8219.
34. Chen K-C, Yeh C-J, Kuo J-F, Hsieh C-L, Yang S-F, Wang C-H. Footprint analysis of Flatfoot in preschool-aged children. Eur J Pediatrics. 2011;170:611–7.
35. Wenger DR, Mauldin D, Speck G, Morgan D, Lieber RL. Corrective shoes and inserts as treatment for flexible Flatfoot in infants and children. JBJS. 1989;71(6):800–10.
36. Bijur PE, Silver W, Gallagher EJ. Reliability of the visual analog scale for measurement of acute pain. Acad Emerg Med. 2001;8(12):1153–7.
37. Myles PS, Troedel S, Boquest M, Reeves M. The pain visual analog scale: is it linear or nonlinear? Anesth Analgesia. 1999;89(6):1517.
38. Jiang Y, Wang D. Design and preliminary validation of individual customized insole for adults with flexible flatfeet based on the plantar pressure redistribution. Sensors. 2021;21(5).

Publisher's note