




Systematic Review

# Mixed Comparison of Intervention with Assistive Devices for Plantar Pressure Distribution and Anatomical Characteristics in Adults with Pes Cavus: Systemic Review with Network Meta-Analysis

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**Abstract:** Background: Pes cavus is a multiplanar foot deformity with an abnormal plantar pressure distribution and an overhigh medial longitudinal arch (MLA). Its causes are complex. In the past, people have usually focused on clinical surgery for pes cavus. However, this is not necessarily the best choice for some patients with non-ongoing or mild symptoms. In the 21st century, studies have just begun to focus on assistive devices intervention for pes cavus, which has been proven to be an effective non-surgical treatment. However, the effectiveness of assistive devices for patients with arched feet of any etiology has not been evaluated and evidence-based guidelines for clinical treatment options are lacking. Methods: A systematic review and network meta-analysis were performed, employing a comprehensive search across the databases of Web of Science, PubMed, as well as Scopus. The selected studies adhered to specific eligibility criteria, which included: (1) involving patients with pes cavus; (2) interventions with assistive devices; and (3) outcome measures of plantar pressure distribution and anatomical characteristics (MLA). Meanwhile, the standard mean difference was selected as the effect size. Results: A total of three studies were selected, and the authors achieved an agreement on the risk of bias with a kappa value equal to 0.74. According to the results of network meta-analysis, customized foot orthotics compared to other devices (lace-up ankle-support brace, semirigid brace) demonstrated the highest likelihood of being the most effective in optimizing plantar-pressure distribution among pes cavus patients. On the other hand, wearing hard custom foot orthotics compared to other devices (soft custom foot orthotics, off-the-shelf orthotics) showed the greatest potential in improving the medial longitudinal arch (MLA) of pes cavus patients. Discussion: Although becoming better than wearing regular footwear, wearing lace-up ankle-support braces or semirigid braces might not be optimal choices for treatments of pes cavus with the potential mechanism that the internal force created by the fixation of the proximal joint might be much less than the ground reaction force loaded on the distal segments that touch the ground. It could be concluded that foot orthotics show great potential in treating pes cavus under non-surgical conditions. This systematic review could provide valuable evidence for future research and clinical practice. Other: The PROSPERO Registration Number is CRD42022349687.

**Keywords:** pes cavus; assistive devices; foot plantar pressure; MLA; network meta-analysis



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## 1. Introduction

Clinically, the term “pes cavus” is used to present a kind of deformity of the medial longitudinal arch (MLA), which has a prominent anatomical characteristic of its abnormal elevation. The accurate description of pes cavus includes numerous foot deformities in multiple planes. At the skeletal level, pes cavus is characterized by plantarflexion of the first metatarsal, wedge-shaped forefoot bones, and bony prominences on the dorsal aspect

of the navicular and cuboid bones. These characteristics commonly result in foot pronation, excessive supination, claw toes, and other foot deformities on the foot level.

Individuals with pes cavus may experience increased stiffness and reduced shock absorption in the lateral aspects of the forefoot and rearfoot, as well as heightened pressure on the foot [1], that can result in increased foot instability, muscle or ligament overstrain, and dysfunction, which can potentially increase the risk of an ankle injury. Specifically, the inward rolling of the foot and ankle caused by the high arch structure can lead to lateral overloading of the foot and ankle structures, potentially compromising foot and ankle function. These effects can hinder athletic performance and increase the likelihood of injury [2]. As a result, the neural and muscle control of the ankle joint can be weakened [3].

The true incidence rate is not yet clear. According to the relevant literature, the incidence rate of pes cavus appears to increase with age, ranging from 2% at 3 years old to 7% at 16 years old [4]. The incidence rate of pes cavus may be higher in the adult population, estimated to be between 10.5% and 25% [5,6]. An estimated 60% of individuals with cavus feet experience foot pain, including conditions such as metatarsalgia, sesamoiditis, or plantar heel pain. It is thought that these conditions are linked to the atypical distribution of pressure on the sole [7].

The etiology of pes cavus encompasses several factors, including neurogenic, congenital, traumatic, and idiopathic causes. Contributing factors to the development of pes cavus involve muscle weakness and imbalances resulting from neuromuscular disorders, residual equinovarus foot present since birth, bone deformities following trauma, peroneal tendon rupture, plantar fasciitis, as well as a shortened Achilles tendon. Currently, based on clinical observations, the medical community generally recognizes pes cavus as one of the results of neurological diseases, and most cases are idiopathic cases that include genetic predisposition [8].

Due to the complex etiology and developmental mechanism of pes cavus, a unified treatment plan cannot be determined in clinical practice. For severe pes cavus patients, such as those with severe hindfoot varus caused by neurological diseases, surgical treatment is necessary since conservative physical therapy cannot solve the endogenous problem [9], but it can play a preventive role [1]. For mild and non-progressive idiopathic pes cavus patients, physical therapy is also a good choice [10]. In real life, there are many pes cavus patients like this, and physical therapy may have better therapeutic effects [9], helping to alleviate pes cavus pain, and correct foot posture and gait. In the clinical treatment of pes cavus, there is a strong emphasis on joint preservation therapy, especially in patients with pes cavus who have flexible joints, but the evidence base for such treatment is extremely limited [11]. Considering the slow progression of pes cavus and its long-term adverse effects on foot biomechanics, the medical community generally recommends timely early intervention for pes cavus. It is helpful for clinical treatment, and it can also play a certain role in the operation of joint preservation [12]. Compared with surgical intervention, conservative physical therapy reduces the risk of surgery.

There are many physical therapy methods used to treat pes cavus, among which foot orthotics are the most common treatment method. Orthotics can relieve discomfort and pain caused by pes cavus by providing appropriate support and adjustment to the foot, and also improve foot function [13–18] by redistributing the load on the plantar surface [10]. Studies have shown that the comfort level of the heel, forefoot, and edge regions of patients wearing semi-custom orthotics has significantly improved [19,20]. Additionally, considering the chronic ankle instability induced by pes cavus, ankle braces may also serve as a non-surgical intervention to prevent and alleviate pes cavus symptoms, redistributing the load on the sole. However, the mechanism of its effect on preventing and alleviating pes cavus needs further investigation [21].

The choice of assistive devices in the clinic between ankle-supported devices or custom foot orthotics and other devices is difficult to determine. Although treatment should be tailored to the cause, it makes sense to select a universal device for intervention in pes cavus patients with any cause. One noteworthy point is that since 2000, research has only

just started to focus on orthotics treatment and symptoms related to pes cavus, particularly metatarsalgia [7]. However, in clinical practice, there is currently no evidence-based guideline for the physical therapy of pes cavus. Moreover, there is still some contradictory evidence regarding the efficacy of the physical therapy mentioned above. For example, the mechanism of foot orthotics treatment is still not clear and still under exploration [22].

The current study has not compared the effectiveness of different assistive device interventions in treating pes cavus. Therefore, to systematically sort out the related research on the selection of physical therapy for pes cavus and their corresponding prognostic effects, providing relatively high-level evidence-based evidence for the future clinical practice of pes cavus physical therapy, it could provide valuable information and recommendations.

The objective of this systematic review is to assess the effectiveness of assistive device interventions in treating pes cavus by comparing their efficacy.

This article adheres to the PRISMA 2020 checklist [23], a comprehensive 27-point guideline designed to ensure uniform reporting of systematic reviews. The checklist covers all essential aspects of the review, including the introduction, methodology, results, discussions, and references. By following the PRISMA 2020 Checklist, we have aimed to ensure that this systematic review is reported completely, transparently, and consistently, meeting the high standards required for clinical practice and providing trustworthy and high-quality evidence.

## 2. Methods

### 2.1. Eligibility Criteria

The eligibility criteria of this systematic review were as follows: (1) Participants: This systematic review incorporated studies that enrolled individuals with pes cavus; (2) Interventions: We identified the effects of interventions with assistive devices such as custom foot orthotics, ankle braces, etc. for the correction of pes cavus. Also included are cross-sectional findings, including the immediate effects of the Intervention with assistive devices. It should be emphasized that the use of oral analgesics, massage, and physical therapy was allowed during the interventions. (3) Comparators: The Bayesian methods to generate reliable intervals and sequencing probabilities to evaluate the overall effectiveness of different treatments. The processing is ranked according to the magnitude of the estimated effect, and then averaged over all samples to determine each rank, for example, first level, second level, etc. [24–27]. Network meta-analysis is useful to mix and compare interventions indirectly by plotting the estimated probabilities against the rank [28]. (4) Outcomes: Since previous research has established that there is a strong correlation between the perceived pain experienced by individuals with pes cavus and the plantar pressure in the forefoot and midfoot, as well as the medial longitudinal angle (MLA) [7,29], this review chose the normalized plantar pressure in forefoot and midfoot, as well as the MLA as the outcome measures. Foot pressure distribution can be measured using motion capture instruments such as Vicon and Motion Analysis. Meanwhile, the measurement of MLA is typically accomplished by utilizing pressure sensor-based foot pressure analysis systems, which analyze the pressure distribution on the foot. Additionally, medical imaging techniques can also be employed to measure MLA. (5) Study Design: Controlled trials were exclusively used.

The exclusion criteria of this systematic review were categorized as follows: (1) patients with musculoskeletal disorders or clinically diagnosed contraindications to exercise; (2) pregnant patients, patients with recent foot trauma, or those who have undergone lower limb surgery recently or have been wearing ankle-foot orthotics all of the time; (3) intervention measures that do not meet the requirements, such as injections or surgery; (4) experiments that have been published as abstracts with insufficient or no data in the full text; (5) inconsistent inclusion criteria and outcome measures.

## 2.2. Information Sources

The databases PubMed, Scopus and Web of Science were searched from 1963 up to May 2023, which covers the time frame since the term “pes cavus” (or “cavovarus”) was introduced in 1963 [30]. Only articles that have been peer-reviewed and written in English were deemed suitable for the search, selection, and screening process of this review. Furthermore, the reference lists of the included studies were meticulously examined, and efforts were made to identify relevant studies in grey literature. In cases where data were incomplete, the authors of the respective studies were contacted to request the necessary information.

## 2.3. Search Strategy

A methodology of study search according to Boolean logic was employed, guided by the following principles: (1) relevant English keywords about the condition were selected from the title or abstract, such as ‘pes cavus’ and ‘cavovarus’; (2) title that mentioned “mice” and animals such as “dog” and “mouse” were excluded; (3) titles containing terms such as “review”, “design”, “protocol” were excluded to ensure focus on potential trials. (4) abstracts that mentioned the intervention pes cavus trial as having a control group or being a randomized controlled trial were considered; (5) abstracts that mentioned interventions involving assistive devices for patients with pes cavus were considered. To enhance the sensitivity and specificity of the search strategy, two independent reviewers (Caiting Zhang and Yining Xu) screened the titles of all identified trials to identify potential trials, followed by abstract screening. Additionally, a third independent librarian (Jiao Li) was engaged to review and refine the search strategy, including checking for synonyms and alternative terms, ensuring maximum rigor in the search process.

## 2.4. Selection Process

The retrieved studies were disposed of by EndNote X9 (Thomson Reuters, Carlsbad, CA, USA) for further processing. The selection process is conducted by the two authors (Caiting Zhang and Yining Xu). If there is disagreement, a third author will intervene in the evaluation (Yaodong Gu) negotiation. The details of the search process can be found in the Supplementary File.

## 2.5. Data Collection Process

Data collection was carried out by two authors (Caiting Zhang and Yining Xu) independently, and the collected data was then reviewed by an independent reviewer (Yaodong Gu) for further analysis and validation.

## 2.6. Data Items

The data in this systematic review were extracted, recorded, and stored to encompass the following variables: (1) participant characteristics: This includes relevant details about the participants such as their average age, population type, and distribution by gender; (2) intervention program details: This encompasses comprehensive information about the intervention programs, including their names, specific details, and categorization; and (3) outcome measure results: This encompasses the recorded results of the outcome measures. It includes the sample sizes for each study, the recording times, and mean values accompanied by their corresponding standard deviations for each recording to different endpoints.

## 2.7. Assessment for Risk of Bias

The evaluation of the potential bias risk of each included study was conducted by using the Cochrane Assessment Tool for Risk of Bias by two authors (Yining Xu and Yaodong Gu) [31]. Based on the guideline of the tool, the overall bias risk categorization in a study is determined by the presence of unclear or high-risk domains. A study will be classified into “low risk of bias” should not have two or more unclear risk items and

should also not have any high-risk factors (inclusive). If a study has three or more items with unclear risk but no items with high risk will be classified as having a “moderate risk of bias”. If a study has >1 item with high risk will be classified into the group “high bias risk”.

The inter-rater agreement among the two independent reviewers who assessed all included studies was evaluated using Cohen’s kappa value. In situations where the reviewers could not reach a consensus, an independent arbiter was consulted to resolve any disagreements.

### 2.8. Effect Measures

Considering the potential variations in outcome measures across the included studies, the effect size reported in this review was standardized as the mean difference (SMD) accompanied by its standard error (SE). By Cohen’s criteria, an SMD exceeding 0.8 was classified as a large effect size, an SMD between 0.5 and 0.8 was regarded as a moderate effect size, an SMD between 0.2 and 0.5 was considered a small effect size, and an SMD below 0.2 was deemed a very small effect size [32].

### 2.9. Synthesis Methods

#### 2.9.1. Synthesis of Information

The synthesis of information provided by included studies was organized in a table, which also included the significant findings related to the outcome measures reported in each of the studies analyzed. The detailed data for each of the outcome measures can be found in the Supplementary File.

#### 2.9.2. Data Pre-Processing

A sole independent researcher performed data pre-processing and analysis using Microsoft Office Excel. The effect size for pes cavus in each intervention with assistive devices was calculated individually using the following equations,

$$\text{SMD} = (X_1 - X_2) / S_c \times [1 - 3 / (4 \times N - 9)] \quad (1)$$

$$\text{SE}(\text{SMD}) = [(n_1 + n_2) / (n_1 \times n_2)] + [\text{SMD}^2 / 2 / (n_1 + n_2 - 3.94)]^{0.5}. \quad (2)$$

$X_1$  and  $X_2$  in Equation (1) represented the mean values of the data before and after intervention,  $N$  in Equation (1) represented the sample size of the group, while  $n_1$  and  $n_2$  were in Equation (2) were the sample size before and after intervention. Therefore if there was no participant lost follow-up or the data analysis of the study was according to the intention-to-treat principle,  $n_1$ ,  $n_2$ , and  $N$  would be in same value [33,34].

To ensure the accuracy and reliability of the pre-processed data, we asked another independent author to conduct a review of all of the original data ultimately included in the study, as well as the pre-processed results, to identify and correct any errors that may have occurred during the data analysis phase.

#### 2.9.3. Data Synthesis

The data processing and evidence pooling was conducted using the ADDIS software (Aggregate Data Drug Information System, Version 1.16.6, <https://drugis.org/>, accessed on 28 May 2023). ADDIS facilitated the amalgamation of processed data, allowing for the computation of effect sizes and the generation of the outcome results.

### 2.10. Reporting Bias Assessment

By the Tool for Assessment of Bias Risk of Cochrane Collaboration, the evaluation of potentially biased reporting in an included study is conducted using the following criteria: (1) If the study is linked to a registration number and the disclosed results align completely with the registered results, it is considered to have a minimal risk of biased reporting; (2) if a study is linked to a designated protocol identifier but the results disclosed in the article do

not fully align with the actual findings, it is classified to high risk of reporting bias; and (3) when a study has no registration identifier, the risk of selective reporting bias is regarded as uncertain [31].

### 2.11. Network Meta-Analysis

#### 2.11.1. Network Geometry

Bayesian simulation models use network geometry to represent the robustness of evidence, the type of intervention, and the number of interventions. In the network geometry, each intervention included in the analysis is represented as a node, and the lines connecting the nodes represent a direct comparison. The number of arms is indicated by the numerical value presented in each row [26].

#### 2.11.2. Model Consistency Analysis

To ascertain the reliability of the network meta-analysis, the primary emphasis was placed on evaluating the consistency of the evidence framework. This involved evaluating factors such as homogeneity, similarity, and the consistency hypothesis [27]. If a closed-loop structure were to emerge during the software's evidence analysis, the outcomes of mixed interventions might exhibit inconsistencies. We would have employed two approaches to detect the presence of such inconsistencies: (1) by comparing the standard deviations of random effects between the consistent and non-consistent models, we could have assessed the level of agreement within the intervention. If the standard deviations of both models aligned, it would have indicated a strong consensus regarding the intervention; (2) through node splitting analysis, the  $p$ -values calculated by the software would have been checked to evaluate the applicability of the model. The analysis would have been conducted in a Bayesian framework, where the analysis would have examined the consistency of direct and indirect evidence across the split nodes, utilized intensive computation, and ensured statistical significance by determining the Bayesian  $p$ -value associated with each node. If the Bayesian  $p$ -value of both evidence obtained directly and evidence obtained indirectly through comparison was  $>0.05$ , then the consistency model could have been used [35]. If there were no inconsistencies or closed loops in the resulting evidence structure, a consistency model could have been used to determine the comparative effectiveness between multiple interventions [36]. On the other hand, the network meta-analysis would have been presented using the rank probability plot in the consistency model when comparing indirect interventions for multiple measures included in the adjusted study [37].

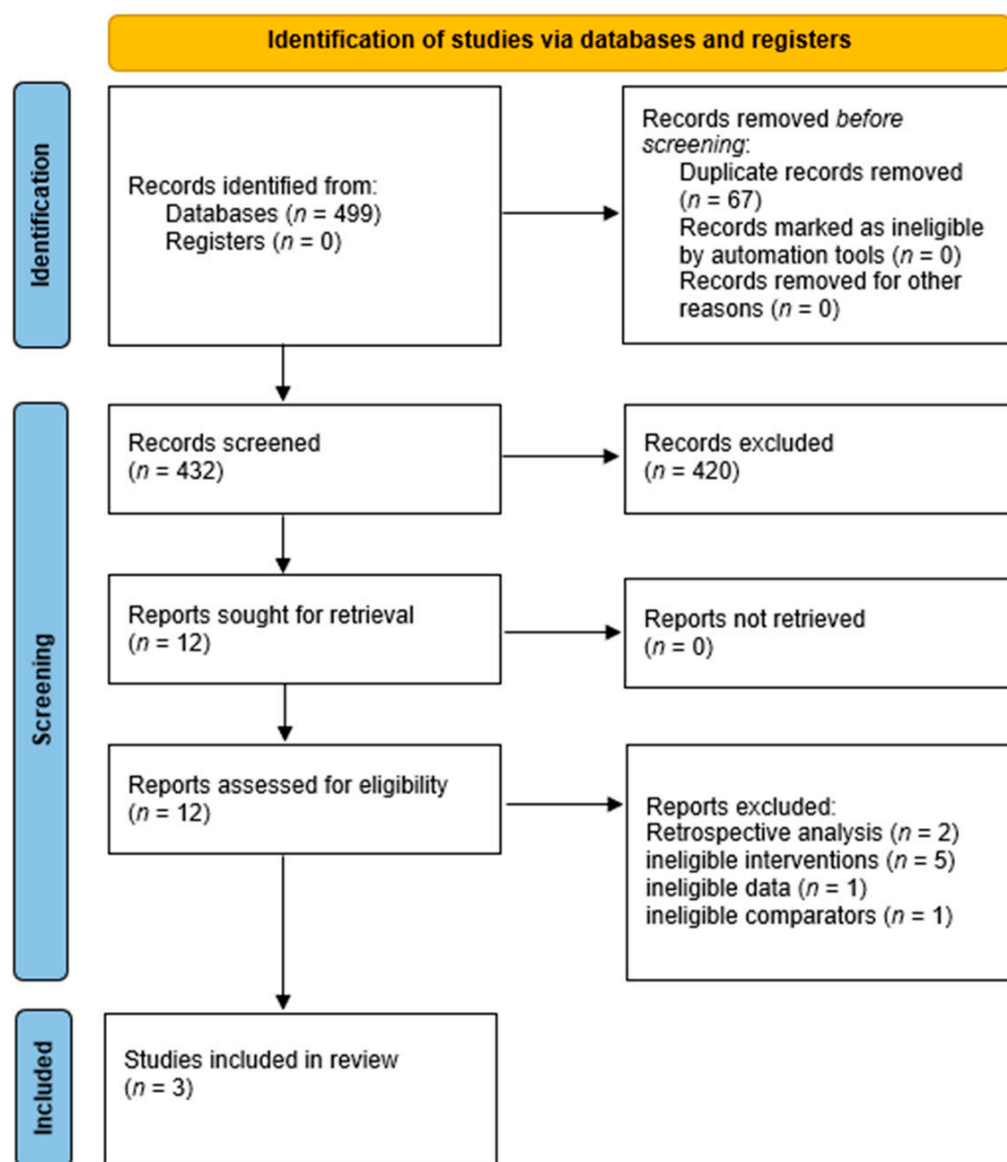
#### 2.11.3. Ranking of Measures and Probability

We would have evaluated the ordering and probability and confirmed that the total percentage of no columns per row would have been equal to 1.00 (100%). Multiple interventions would have been ranked according to the likelihood of having the most or least advantage.

## 3. Results

### 3.1. Search, Selection, and Screening of Studies

After the selection and screening of 499 titles and abstracts, 67 duplicated studies were removed, and a total of 432 studies were taken into account during the screening procedure. Then, 12 trials mentioned intervention with assistive devices for pes cavus in the abstract, of which 2 were excluded as retrospective analyses of previous trials, 5 were excluded as ineligible interventions, 1 was excluded as ineligible comparators, 1 was excluded as having no raw data, and 3 were included in the final analysis [13,21,38]. The flow diagram is presented in Figure 1.



**Figure 1.** The flow diagram of study selection.

### 3.2. Study Characteristics

According to the selected studies, three trials reported instrumenting intervention with pes cavus, and one reported foot orthotics intervention with 154 pes cavus at a three-month follow-up [13]. Two other experiments were cross-sectional studies, one of which reported before and after the angle of the medial longitudinal arch of the footwear and barefoot in 4 pes cavus with hard custom foot orthotics, soft custom foot orthotics, and off-the-shelf orthotics [38], and the other reported walking tasks in 11 pes cavus with unbraced, lace-up ankle braces, and semirigid braces [21]. The detailed information and main results of studies included in the analysis were provided in Table 1, offering a comprehensive listing.

**Table 1.** Characteristics and main information provided by each included study.

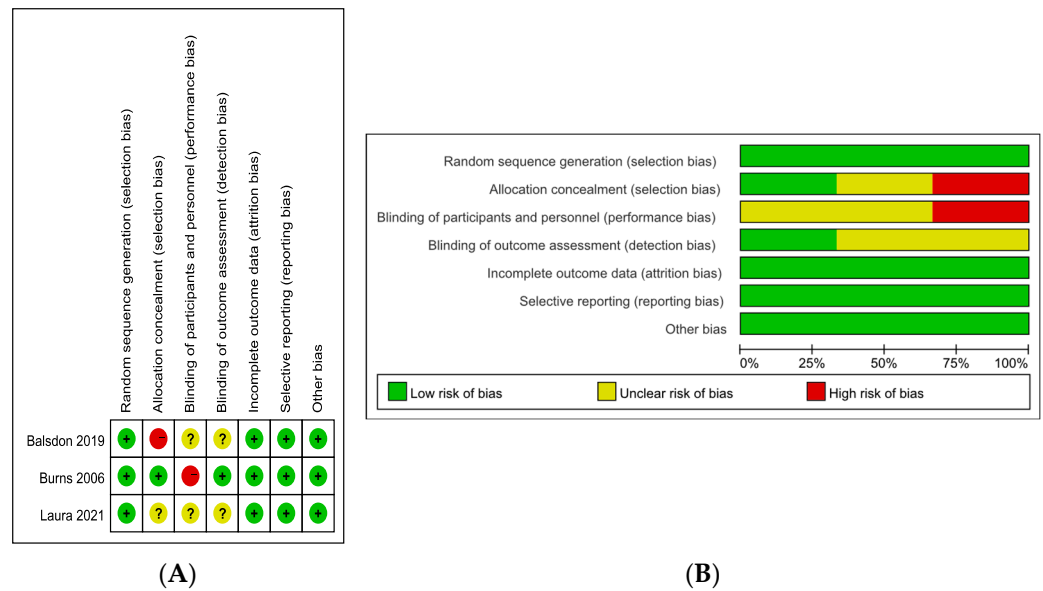
Study	Design	Participants			Time	Interventions		Outcome Measures	Main Findings
		Population	Age	Gender Ratio (F/M)		Type	Protocol		
Burns 2006 [13]	RCT	Participants with chronic muscle skeletal foot pain and bilateral cavus feet	/	Unclear	3 months	<ul style="list-style-type: none"> <li>Control</li> <li>Custom Foot orthotics</li> </ul>	Wear intervention for most of their footwear-wearing time.	Plantar Pressure	<ul style="list-style-type: none"> <li>Custom foot orthotics can significantly reduce plantar pressure load on the entire foot, back foot, and front foot.</li> <li>In the mid-foot area, plantar pressure increased with custom plantar orthotics</li> </ul>
Balsdon 2019 [39]	Cross-sectional study	A total of 12 individuals were recruited from each category of feet, namely individuals with normal arches, pes cavus, and pes planus.	29.1	/	/	<ul style="list-style-type: none"> <li>Control</li> <li>Hard custom foot orthotics</li> <li>Soft custom foot orthotics</li> <li>Off-the-shelf foot orthotics</li> </ul>	Each group performs the walking task marker less fluoroscopic diastereomeric analysis	MLA	<ul style="list-style-type: none"> <li>The MLA of the Hard custom foot orthotics group was reduced.</li> <li>The MLA of the Soft custom foot orthotics group was reduced.</li> <li>The MLA of the Off-the-shelf foot orthotics group was increased</li> </ul>
Dickerson 2021 [21]	Cross-sectional study	Healthy young adults	23.1 ± 2.5	11/25	/	<ul style="list-style-type: none"> <li>Control</li> <li>Lace-up ankle-support brace</li> <li>Semirigid brace</li> </ul>	Complete the walking task	Plantar Pressure	<ul style="list-style-type: none"> <li>Lace-up ankle-support brace and Semirigid brace increase mid-foot pressure and reduce forefoot pressure, and the Semirigid brace is more significant</li> </ul>

Control: regular footwear; /: unclear; RCT: randomized controlled trial.



### 3.3. Risk of Bias

According to Figure 2B, it could be found that three studies with a low risk of bias. The agreement among several authors regarding this risk of bias yielded a kappa coefficient of 0.74.



**Figure 2.** The assessment of bias risk. (A) summary of bias risk; (B) graph of bias risk [13,21,38].

### 3.4. Network Meta-Analysis

It could be seen in Figure 3, which presents the graphical representation of the evidence structures for the comparisons, that the included interventions involved Control, Lace-up ankle-support brace, Semirigid brace, and Custom foot orthotics, Hard custom foot orthotics, Soft custom foot orthotics, and Off-the-shelf orthotics. A comprehensive overview of the outcomes from both the consistency and inconsistency analyses is available in Table 2.

**Table 2.** The outcomes of the consistency and inconsistency analysis.

Outcome Measures	Interventions	Standard Deviations of Random Effects	
		Mean Estimate in the Context of a Consistency Model (95%CI)	Mean Estimate in the Context of an Inconsistency Model (95%CI)
Forefoot plantar pressure	Control, Lace-up ankle-support brace, Semirigid brace, Custom foot orthotics	0.29 (0.02, 0.58)	0.29 (0.02, 0.57)
Midfoot plantar pressure	Control, Lace-up ankle-support brace, Semirigid brace, Custom foot orthotics	0.09 (0.00, 0.19)	0.10 (0.01, 0.19)
MLA	Control, Hard custom foot orthotics, Soft custom foot orthotics, Off-the-shelf orthotics	0.55 (0.03, 1.06)	0.54 (0.04, 1.07)

Control: regular footwear.

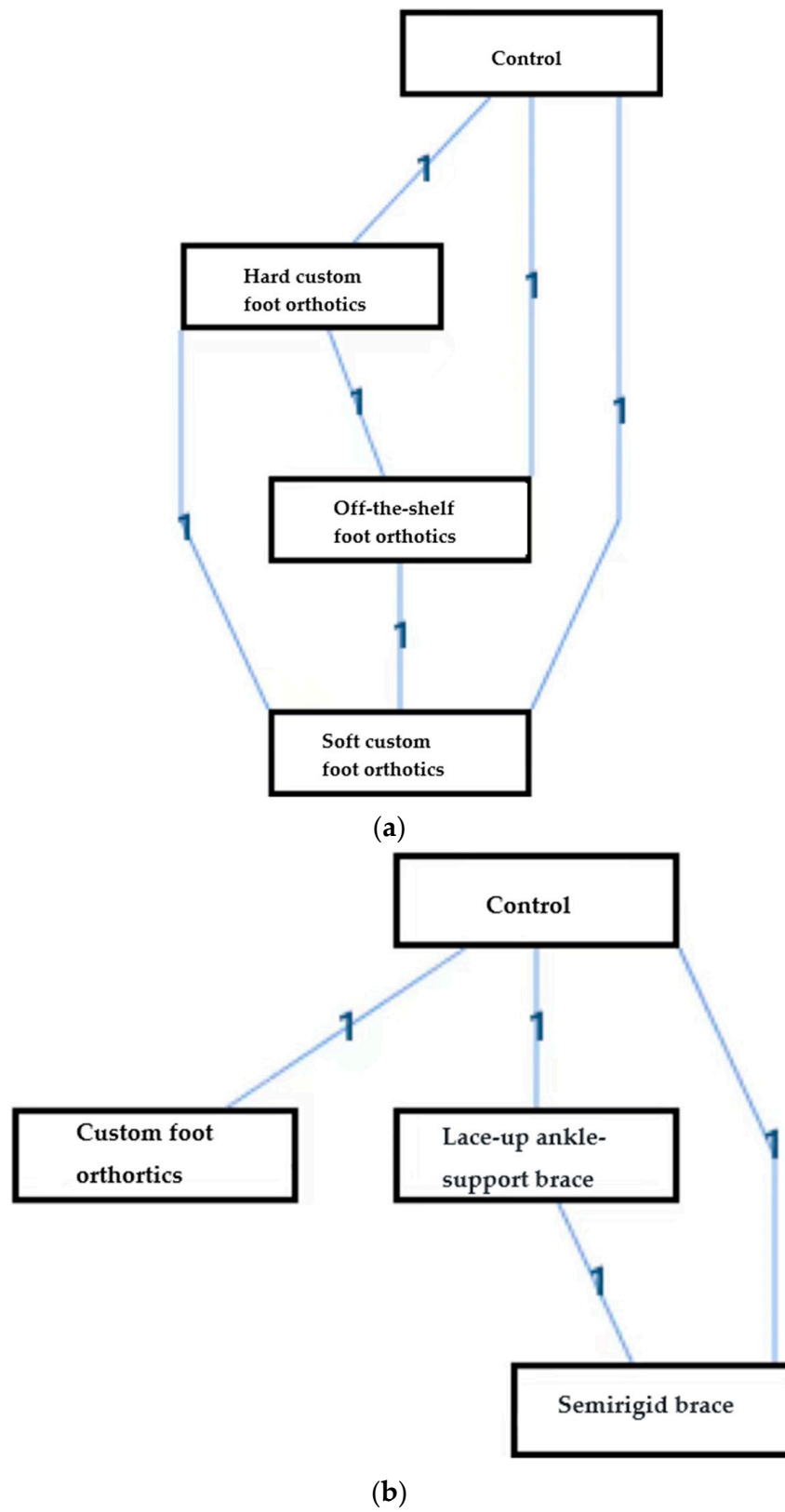
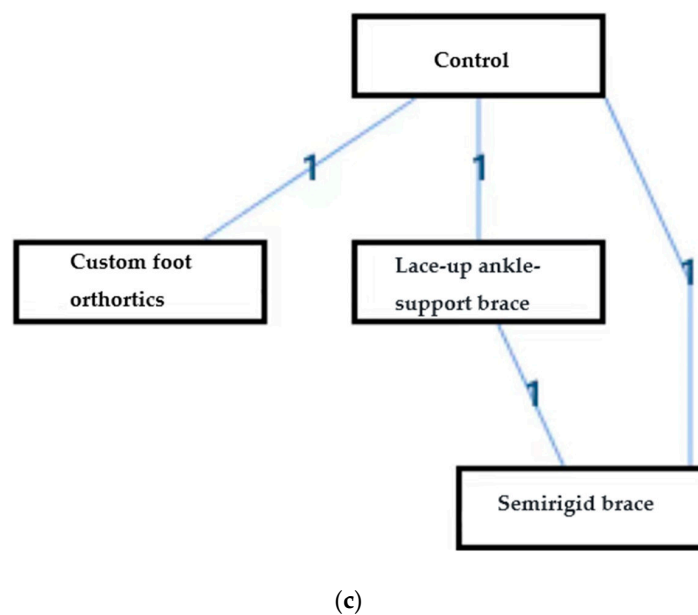


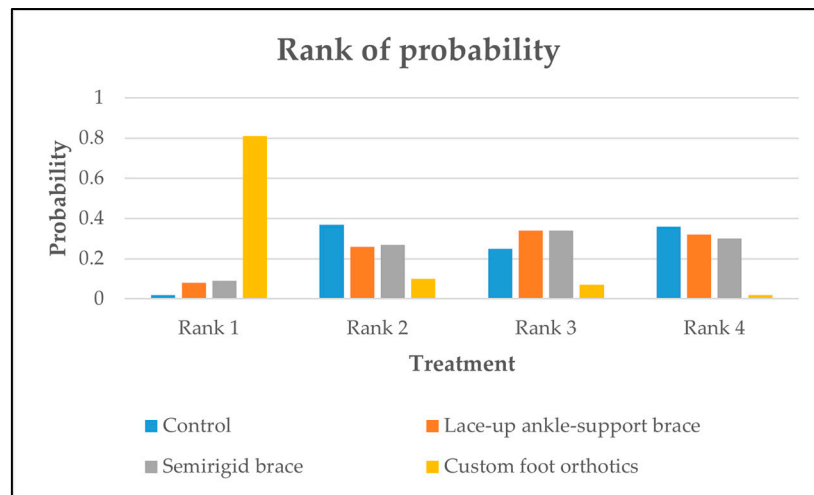
Figure 3. Cont.



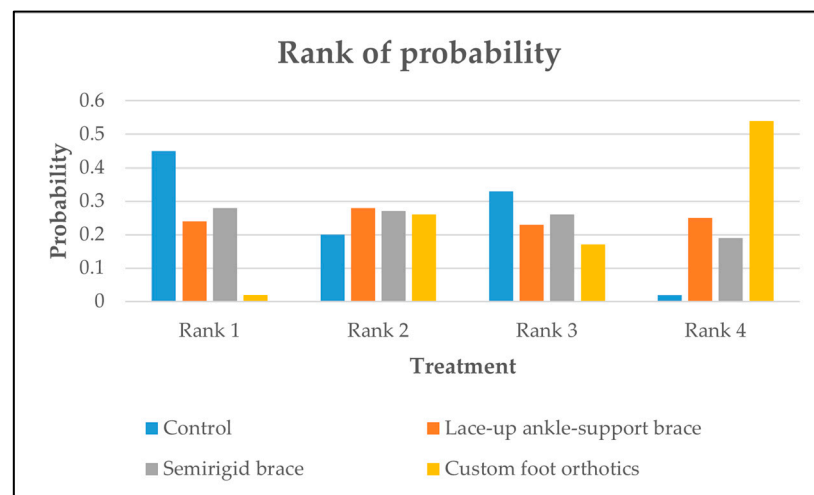
**Figure 3.** Evidence structures of each mixed comparison. (a) MLA; (b) Forefoot plantar pressure; (c) Midfoot plantar pressure.

Figure 3 portrays the evidential framework of the network meta-analysis, which includes three types of interventions for assessing the effects on forefoot plantar pressure, midfoot plantar pressure, and MLA. These interventions are compared within groups. The analysis of consistency and inconsistency is presented in Table 2, revealing robust consistency across all evidence structures. Notably, the random-effects standard deviations derived from both the consistency and inconsistency models were found to be identical. Therefore, the consistency model proved to be a robust approach for performing network meta-analysis. Figure 4, as well as Table 3, shows the probability rankings for each intervention in a mixed comparison. It is important to note that plantar pressure and MLA of the forefoot are continuous data, and the higher value is considered to be better. Consequently, in the probability rank for forefoot plantar pressure and MLA, Rank 1 represents the best performance, whereas, in midfoot plantar pressure, Rank 4 indicates superior performance. The supplementary material shows the outcomes of the network meta-analysis. This table illustrates the variations in synthesized effect sizes among different pairs of interventions.

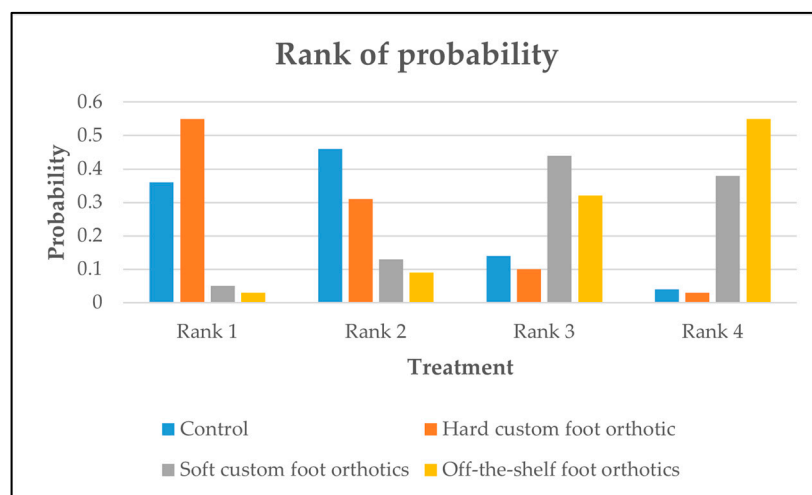
Referring to the probability rankings outlined in Table 3, custom foot orthotics may be the best choice of intervention with assistive devices for forefoot plantar pressure (0.81 in Rank 1 and 0.02 in Rank 4), lace-up ankle-support brace (0.08 in Rank 1 and 0.32 in Rank 4) and semirigid brace (0.09 in Rank 1 and 0.30 in Rank 4), two interventions that did not show a higher probability of selection compared to the control group wearing regular footwears (0.02 in Rank 1 and 0.36 in Rank 4). In midfoot plantar pressure, custom orthotics demonstrated the highest probability of selection, with a 0.02 ranking in Rank 1 and a 0.54 ranking in Rank 4, while lace-up ankle-support brace (0.24 in Rank 1 and 0.25 in Rank 4) and semirigid brace (0.28 in Rank 1 and 0.28 in Rank 1 and 0.19 in Rank 4) had a better selection probability relative to the control group wearing regular footwears (0.45 in Rank 1 and 0.02 in Rank 4). In terms of MLA, the selection probabilities suggest that hard custom foot orthotics ranked highest (0.55 in Rank 1 and 0.03 in Rank 4), indicating the most favorable outcome. Nonetheless, when compared to the non-intervention control group, comprised of individuals wearing regular footwear (with effect sizes of 0.36 in Rank 1 and 0.04 in Rank 4), soft custom foot orthotics (with effect sizes of 0.05 in Rank 1 and 0.38 in Rank 4) and off-the-shelf orthotics (with effect sizes of 0.03 in Rank 1 and 0.55 in Rank 4) exhibited relatively lower effectiveness.



(a)



(b)



(c)

**Figure 4.** The rank of the probability of each intervention in mixed comparisons. (a) Forefoot plantar pressure; (b) Midfoot plantar pressure; (c) MLA.

**Table 3.** The ranking probability of each comparison between mixed interventions.

Outcome Measures	Interventions	Rank 1	Rank 2	Rank 3	Rank 4
Forefoot plantar pressure	Control	0.02	0.37	0.25	0.36
	Lace-up ankle-support brace	0.08	0.26	0.34	0.32
	Semirigid brace	0.09	0.27	0.34	0.30
	Custom foot orthotics	0.81	0.10	0.07	0.02
Midfoot plantar pressure	Control	0.45	0.20	0.33	0.02
	Lace-up ankle-support brace	0.24	0.28	0.23	0.25
	Semirigid brace	0.28	0.27	0.26	0.19
	Custom foot orthotics	0.02	0.26	0.17	0.54
MLA	Control	0.36	0.46	0.14	0.04
	Hard custom foot orthotic	0.55	0.31	0.10	0.03
	Soft custom foot orthotics	0.05	0.13	0.44	0.38
	Off-the-shelf foot orthotics	0.03	0.09	0.32	0.55

Control: regular footwear.

#### 4. Discussion

A network meta-analysis approach was utilized to provide a comprehensive evaluation of the effectiveness of different interventions involving assistive devices for patients with pes cavus in this systematic review. The results provide evidence-based with higher quality guidelines for clinicians on intervention with assistive devices and prevention strategies for pes cavus.

Notably, our initial search, which excluded duplicate options, found 432 articles with selected keywords in their abstract and title. Most articles compare experimental studies of clinical treatment, with a primary emphasis on evaluating surgical cases. After incorporating the assistive device aspect into our search, we found that only 12 articles mentioned assistive devices in the abstract. After further screening, we included only three articles that met all of the criteria. Some important findings of this review can be summarized as follows: Firstly, customized foot orthotics may be the best Intervention with assistive devices option to optimize plantar pressure distribution for feet with pes cavus. This advantage lines in both forefoot and midfoot regions. Moreover, lace-up ankle-support braces and semirigid braces may not be optimal in terms of achieving uniform foot pressure distribution similar to individuals with normal feet, but they may still be better than ordinary footwear. Finally, from the anatomical perspective, custom orthotics can help reduce MLA motion in pes cavus patients, but off-the-shelf foot orthotics are weaker in reducing MLA motion.

The first finding of this analysis is that custom foot orthotics are effective in mitigating plantar pressure distribution in pes cavus patients. Some previous studies have demonstrated that customized foot orthotics can effectively intervene and prevent pes cavus, which is in line with the main findings of this review. For example, a study by Benedetti's team that was published in 1997 examined the gait patterns of individuals suffering from painful pes cavus [39] and found that the use of custom orthotics resulted in improved gait patterns and a wider distribution of loads across the plantar surface, indicating a successfully unloaded metatarsal area. In this study, the group that did not use this kind of orthotics was more likely to require surgical correction due to unsuccessful mechanical intervention, potentially caused by limited ability to alter mechanics in the absence of motion. The potential mechanism of the custom orthotics' effect on pain reduction might come from the wider contact surface area of the orthotics and the ability to control compensatory motion and unload the metatarsal heads, concluding that custom orthotics are an effective treatment option for improving gait patterns and reducing pain in patients with pes cavus. Moreover, a study conducted in 2021 provided evidence supporting the effectiveness of custom foot orthotics in altering the probability distribution of plantar pressure during walking. The researchers established a regression equation model and observed a significant change in the dynamic plantar pressure regression factor index after implementing foot orthotics. The study specifically focused on pes cavus patients and highlighted the substantial impact of custom foot orthotics on the regression factor

index. They found that the direction of foot pressure changes exhibited similarities to that observed in individuals with normal feet. The findings demonstrate the positive influence and potential advantages of custom foot orthotics in enhancing gait characteristics and effectively distributing plantar pressure among pes cavus patients [40]. In addition, In a study published in 2021 by Grady et al. [41], it was proposed that pes cavus could reduce foot pain by using custom foot orthotics, which was also related to the redistribution of plantar pressure by custom foot orthotics, resulting in a change in load bearing on each joint.

The second finding of this review is that the ankle brace had an effect on plantar pressure distribution but in pes cavus of any etiology we chose, the performance of ankle braces did not show a significant advantage over custom foot orthotics. However, at present, there are limited numbers of previous studies investigating the effect of ankle brace in patients with pes cavus and the results are various and some of them are in controversy [42–44]. These studies provided limited evidence for clinical practice. The reason might be that in the pes cavus population, compared to the direct effect of custom foot orthotics, the proximal fixation of the proximal joint (ankle joint) caused much less internal force on the distal arch than the ground reaction. Nevertheless, it had some effect. In patients with pes cavus, the choice of ankle brace provides ankle control, alleviates ankle compensation due to foot abnormalities, mainly reduces the risk of an ankle injury, and does not directly affect the foot surface [45,46]. Our results also showed that Lace-up ankle braces and semirigid ankle braces had similar effects on foot pressure distribution, indicating that the selection of categories had no significant impact on the results. Moreover, we found that previous studies, which did not target pes cavus treatment but chose Lace-up ankle brace and Semirigid brace to explore foot pressure distribution [21,47,48], did not give significantly different results caused by different categories. This may suggest that the effect of different categories is weak. While lace-up ankle-support braces and semirigid braces may lower the risk of lower limb injury, their effects on treating foot pressure imbalance in pes cavus, particularly in patients with pes cavus or other foot abnormalities, require further evaluation. Based on current evidence, it is premature to conclude whether ankle supports represent a viable treatment option for foot pressure imbalance, though future research may shed light on their potential as a therapeutic tool.

The third finding of this review indicates that custom foot orthotics significantly impacted the height of the medial longitudinal arch (MLA) compared to the condition where participants wore shoes without orthotics. This suggests that foot orthotics are effective in reducing MLA motion across various foot types. Previous studies have also demonstrated the influence of foot orthotics on MLA not only in people with pes cavus but also in people with different types of plantar deformities. For example, a study published in 2014 included patients with normal foot type, which found that the use of custom foot orthotics resulted in a small increase in arch height index compared to footwear conditions, suggesting that orthotics limited MLA movement [49]. A study published in 2015 reported that the use of custom foot orthotics in runners may have a positive impact on MLA [50], the reason might be that custom foot orthotics may alter the joint Angle of the foot, providing MLA foot support and alleviating plantar fascia strain. It should be mentioned that several studies have also suggested that ankle braces may affect the dynamic MLA motion of clubfeet [51,52], but no relevant evidence has been found to affect pes cavus MLA.

Meanwhile, after considering the findings from a network meta-analysis, it has been found that off-the-shelf orthotics are less effective compared to custom orthotics for patients with pes cavus. Moreover, there is currently limited evidence supporting the use of off-the-shelf foot orthotics in the treatment of pes cavus. Given the diverse etiology, severity, and individual differences among patients with high arches, it suggests that individualized interventions may be necessary for optimal treatment outcomes. This implies that customized approaches tailored to each patient's specific needs with high arches may be more beneficial than generic off-the-shelf orthotics.

There are also some limitations of this review. Firstly, the study pool is limited as only three single-arm studies were included. Secondly, out of the three studies, only one is of high quality, while the other two exhibit moderate bias. Lastly, the inclusion of a control group that consists of participants wearing their regular everyday footwear introduces potential heterogeneity, as each individual may be using different types of footwear.

## 5. Conclusions

To sum up, intervention with different assistive devices has an impact on foot pressure distribution and MLA in patients with pes cavus, and Intervention with assistive devices is effective in treating and preventing symptoms of pes cavus. The findings and previous studies were biased in favor of custom foot orthotics as the best treatment option, but there remains a lack of clarity regarding the safety and practical guidelines for these interventions. Thus, further longitudinal studies are warranted to provide a more robust demonstration in the future.

## 6. Other Information

This systematic review was in line with the PRISMA 2020 guidelines [23]. The screening criteria for literature and the search strategies were collaboratively developed and approved by two independent authors (Caiting Zhang and Yining Xu). PROSPERO Registration Number: CRD42022349897.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app13179699/s1>.

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