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Systematic Review

Outcomes and Safety with Utilization of Metallic Midfoot Wedges in Foot and Ankle Orthopedic Surgery: A Systematic Review of the Literature

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Abstract: The use of midfoot wedges for the correction of flatfeet disorders, such as progressive collapsing foot disorder, has increased greatly in recent years. However, the wedge material/composition has yet to be standardized. Metallic wedges offer advantages such as comparable elasticity to bone, reduced infection risk, and minimized osseous resorption, but a comprehensive review is lacking in the literature. Therefore, the objective of this systematic review was to organize all studies pertaining to the use of metallic wedges for flatfoot correction to better understand their efficacy and safety. This systematic review adhered to PRISMA guidelines, and articles were searched in multiple databases (PubMED, SPORTDiscus, CINAHL, MEDLINE, and Web of Science) until August 2023 using a defined algorithm. Inclusion criteria encompassed midfoot surgeries using metallic wedges, observational studies, and English-language full-text articles. Data extraction, article quality assessment, and statistical analyses were performed. Among 11 included articles, a total of 444 patients were assessed. The average follow-up duration was 18 months. Radiographic outcomes demonstrated that patients who received metallic wedges experienced improvements in lateral calcaneal pitch angle and Meary's angle, with an enhancement of up to 15.9 degrees reported in the latter. Success rates indicated superior outcomes for metallic wedges (99.3%) compared to bone allograft wedges (89.9%), while complications were generally minor, including hardware pain and misplacement. Notably, there were no infection complications due to the inert nature of the metallic elements. This review summarizes the effectiveness, success rates, and safety of metallic wedges for flatfoot correction. Radiographic improvements and high success rates highlight their efficacy. Minor complications, including pain and mispositioning, were reported, but the infection risk remained low. Our results demonstrate that metallic midfoot wedges may be a viable option over allograft wedges with proper planning. Future research should prioritize long-term studies and standardized measures.

Keywords: metallic implants; flat foot deformity; Cotton osteotomy; Evans osteotomy; progressive collapsing foot deformity; systematic review

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1. Introduction

Midfoot wedges have become increasingly popular in recent years for use in the correction of progressive collapsing foot deformity (PCFD). Procedures such as the Evans lateral column lengthening osteotomy and Cotton opening wedge medial cuneiform osteotomy are commonly employed for the treatment of PCFD, and favorable outcomes are well-reported throughout the literature [1,2]. While foot and ankle surgeons are generally in agreement regarding the efficacy of osteotomy-type procedures for PCFD, the choice of wedge material has yet to become universal. With materials ranging from structural autograft, allograft, xenograft, and synthetic substances, the benefits of each material remain reliant on surgeon preference and availability [3]. Moreover, porous titanium, a recent technology which has been utilized extensively within knee and hip arthroplasty [4,5], has recently begun increasing in popularity within foot and ankle orthopedics as a midfoot wedge manufacturing material (Figure 1) [6]. The utilization of metallic wedges for PCFD correction offers several advantages. First, metallic wedges possess a comparable elastic modulus to subchondral bone, enabling durable correction [6]. Second, the risk of infection is minimized as metallic wedges are inert and cannot transmit diseases [6]. Lastly, metallic wedges mitigate osseous resorption through their design, addressing a common problem associated with traditional graft options for midfoot wedges [7].

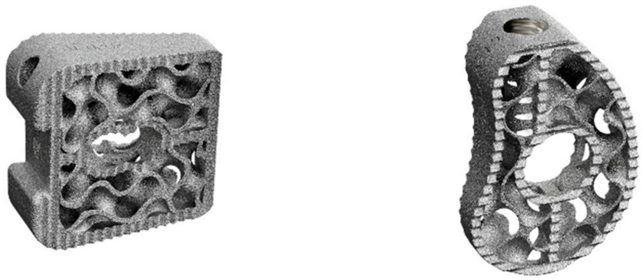

Figure 1. Example of metallic midfoot wedges: Evans osteotomy (**left**) and Cotton osteotomy (**right**).

While the use of porous metallic implants has become more popular in recent years, no review has analyzed the results and safety of these devices multi-institutionally. As studies describing metallic midfoot wedges tend to be limited to one institution, bias and various confounding factors may prevent proper analysis, limiting the justification of their widespread use. Therefore, the objective of this review was to summarize the results of metallic wedges for PCFD correction to properly describe not only the efficacy of these devices, but also to provide a comprehensive description of possible complications to maximize patient safety.

2. Materials and Methods

2.1. Study Creation

This review was performed in agreement with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines as outlined in the literature [8]. This review was not registered prior to completion. The initial search was performed using PubMED, SPORTDiscus, CINAHL, MEDLINE, and Web of Science and included all records retrieved in the five databases via the search algorithm until 8 August 2023. The search algorithm used in this study was wedge AND (pes planus OR flat foot OR flatfoot OR forefoot OR midfoot OR pes OR foot) AND (metallic OR metal OR titanium).

2.2. Eligibility Criteria

Inclusion criteria were articles that examined surgical intervention to the midfoot, articles that utilized metallic wedges for midfoot correction, observational studies, randomized controlled trials, articles in English, and articles with full text. Exclusion criteria were articles that did not examine surgical interventions aimed at the midfoot, articles in which surgical interventions did not use metallic wedges, articles not in English, those with no full text, case reports, and systematic reviews.

2.3. Study Definitions

Within this study, metallic wedges refers to wedges made of various metals, such as titanium, used in midfoot foot and ankle procedures. The bone allograft is another type of wedge that can be used during midfoot surgeries and represents an alternative to metallic wedges in this study. The success rate is defined as successful bony union and is antithetical to non-union.

2.4. Article Screening

This study utilized Rayyan, an online public software commonly used in the literature for systematic reviews [9]. All article screening was performed by a single author. After all articles obtained via the search algorithm in the five databases were retrieved, duplicate articles were manually removed. Then, articles were screened for inclusion by title and abstract, followed by full-text screening. The references of the included articles were searched for articles that could meet the eligibility criteria of this systematic review.

2.5. Data Extraction

Data extraction for this systematic review was performed by one author. The data collected included the first author, year of publication, type of study, type of wedge used (bone graft or metal), number of patients, number of feet operated, cohort descriptions, surgery descriptions, and size of wedges. Furthermore, the data collected included the preoperative and postoperative radiographic outcomes (lateral talus-first metatarsal angle/Meary's angle, anterior–posterior talonavicular coverage angle, lateral calcaneal pitch angle, anterior–posterior talus-first metatarsal angle, and anterior–posterior talocalcaneal angle/Kite's angle), as well as follow-up times, success rates, and complications [10].

2.6. Article Quality Grading

The methodological index for non-randomized studies (MINORS) scale was used for all studies included in this study [11]. Articles were graded via the MINORS scale with comparative studies being out of 24 points and non-comparative studies being out of 16 points [11]. Each item on the MINORS scale was worth 0–2 points [11]. Article quality grading was performed by a single author.

2.7. Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) version 29.0 (Armonk, NY, USA: IBM Corp) was used for any necessary statistical analysis in this systematic review. Descriptive statistics and frequency-weighted means were utilized to describe the data. Meta-analysis was not attempted due to the heterogeneity of the study data and the observational nature of the included articles. Instead, a narrative approach to the systematic review was performed for the current study.

3. Results

3.1. Search Results

In total, 11 articles met the eligibility criteria for inclusion in this systematic review from 113 articles initially retrieved from the five databases [11–21]. All 11 articles were initially found on the five databases and no additional articles were included from further reference searches of the included articles. Refer to Figure 2 for the PRISMA diagram for further information on the search process from initial search to final article inclusion.

3.2. Article Quality Results

All 11 articles included in this systematic review were graded via the MINORS scale as previously noted. The mean MINORS score was 13.8 ± 3.8 points (range, 10.0–20.0) with non-comparative studies (n = 8) having a mean score of 11.6 ± 0.7 points and comparative studies (n = 3) having a mean score of 19.7 ± 0.6 points. Refer to Table 1 for more specific information on the quality grading.

Table 1. The methodological index for non-randomized studies (MINORS) scale for quality grading of the included studies in this systematic review.

Author (Year)	Study Type	Total MINORS Score	Clearly Stated Aim	Inclusion of Consecutive Patients	Prospective Collection of Data	End Points Appropriate to Study Aim	Unbiased Assessment of Study End Point	Follow-Up Period Appropriate to Study Aim	Less than 5% Lost to Follow Up	Prospective Calculation of the Study Size	Adequate Control Group	Contemporary Groups	Baseline Equivalence of Groups	Adequate Statistical Analysis
Au (2022)	Non-comparative	12	2	2	0	2	2	2	2	0	-	-	-	-
Ellis (2011)	Comparative	19	2	2	0	2	2	2	2	0	2	2	1	2
Fraser (2019)	Non-comparative	10	1	2	0	2	2	1	2	0	-	-	-	-
García-Jarabo (2023)	Non-comparative	12	2	2	0	2	2	2	2	0	-	-	-	-
Gross (2015)	Non-comparative	12	2	2	0	2	2	2	2	0	-	-	-	-
Matthews (2018)	Non-comparative	11	2	2	0	2	2	1	2	0	-	-	-	-
Moore (2018)	Non-comparative	12	2	2	0	2	2	2	2	0	-	-	-	-
Romeo (2019)	Comparative	20	2	2	0	2	2	2	2	0	2	2	2	2
Siebert (2021)	Non-comparative	12	2	2	0	2	2	2	2	-	-	-	-	-
Stamatos (2023)	Comparative	20	2	2	0	2	2	2	2	0	2	2	2	2
Tsai (2019)	Non-comparative	12	2	2	0	2	2	2	2	0	-	-	-	-

3.3. Patient Demographics

A total of 444 patients were assessed from the 11 articles included in this systematic review. Of those 444 patients, 364 patients (82.0% of patients) were included in nine articles that reported 409 feet were examined, indicating 45 cases of bilateral surgery. The included patients (n = 444) had a frequency-weighted mean age of 48.8 ± 10.9 years (n = 444, 100.0% of patients reported) with a frequency-weighted mean follow-up of 18.0 ± 12.1 months (n = 437, 98.4% of patients reported). Of the included patients (n = 444), 61 patients received an unspecified wedge type for outcomes (metal or non-metal), 45 patients received bone allograft wedges, and 338 patients received metal wedges in their surgical procedures. Refer to Table 2 for more information.

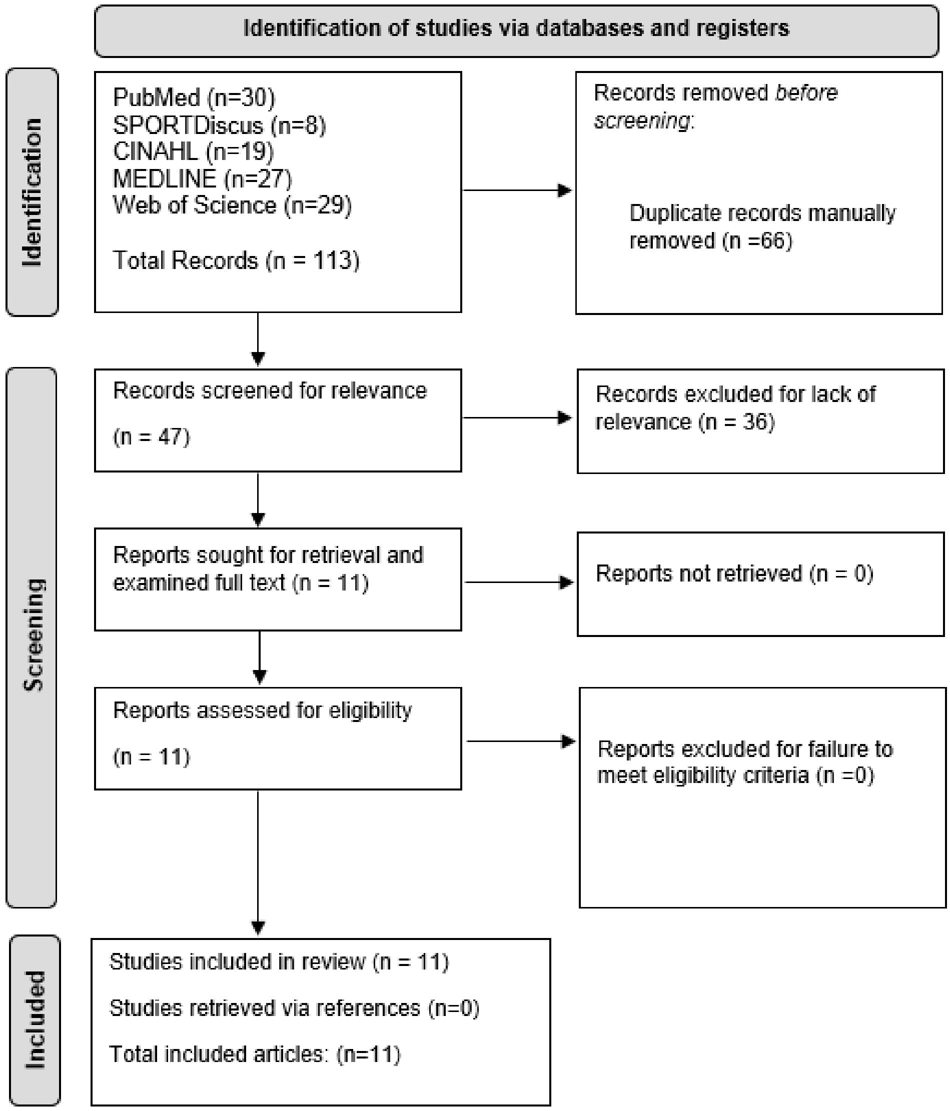

Figure 2. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram for this systematic review, outlining the search process from the initial database search to final article inclusion.

3.4. Radiographic Outcomes after Wedge Utilization

Fraser et al. (2019) reported that metallic wedges in the medial column of the foot appeared to provide successful radiographical outcomes with similar rates of complications when compared to other common corrective foot and ankle procedures [13]. For patients with both preoperative and postoperative measurements, patients (n = 88, 19.8% of patients) who received metallic wedges had a frequency-weighted mean preoperative lateral calcaneal pitch angle of 13.6 ± 0.6 degrees and a frequency-weighted mean postoperative lateral calcaneal pitch angle of 19.2 ± 1.6 degrees, whereas patients (n = 27; 6.1% of patients) who received bone allograft wedges had a mean preoperative lateral calcaneal pitch angle of 12.9 degrees and a postoperative lateral calcaneal pitch angle of 25.4 degrees [13]. Furthermore, Fraser et al. (2019) reported an improvement of 3.1 degrees in patients who received metallic wedges during operative correction of PCFD deformity (n = 31) [13]. For patients with preoperative and postoperative measurements of Meary's angle, patients (n = 139; 31.3% of patients) who received metallic wedges had a frequency-weighted mean preoperative angle of 2.3 ± 15.5 degrees and a frequency-weighted mean postoperative angle of 2.2 ± 4.8 degrees, whereas patients (n = 18; 4.1% of patients) who received bone allograft wedges had a mean preoperative angle of 9.8 degrees and a mean postoperative angle of 1.8 degrees. Fraser et al. (2019) reported a mean 15.9-degree improvement in Meary's angle in 31 patients who received metallic wedges [13]. Similarly, Siebert et al. (2021) reported a mean 13.9-degree improvement in Meary's angle in 7 patients with the use of metallic wedges [19]. Stamatos et al. (2023) compared bone allograft wedges to metallic wedges and found no radiographic differences at six months and one year between both materials for lateral column lengthening procedures [20]. Furthermore, Tsai et al. (2019) found that the use of metallic wedges led to reliable, effective, and stable radiographic outcomes in patients undergoing corrective osteotomy procedures [21]. For more information on additional radiographic outcome measurements, refer to Table 3 for anterior–posterior talonavicular coverage angle, anterior–posterior talus-first metatarsal angle, and anterior–posterior talocalcaneal angle (Kite's angle).

3.5. Success Rates with Wedge Utilization

From the 444 total patients, 205 patients (46.3%) had reported success rates specified by wedge type. Patients receiving metallic wedges (n = 138) had a frequency-weighted mean success rate of 99.3% ± 1.6%, whereas patients receiving bone allograft wedges (n = 27) had a mean success rate of 89.9%. Therefore, pooled data with a relatively small sample size (n = 205) indicate a higher success rate with metallic wedges as compared to bone allograft wedges during midfoot corrective surgery (99.3% versus 89.9%). Matthews et al. (2018) reported that metallic wedges were an efficacious and acceptable method for correction of flexible flatfoot deformities in their study of 34 patients [16]. Moore et al. (2018) reported that the use of metallic wedges in lateral column lengthening had similar results to the results for allograft and autograft in the literature [17]. Gross et al. (2015) found that Evans osteotomy had low non-union rates with improved radiographic correction [15]. Finally, Gracia-Jarabo et al. (2023) concluded that metallic wedges can lead to excellent bone integration in their study [14] (Table 4).

Table 2. Information on the included articles, patient demographics, and surgeries with wedge utilization. The data recorded included the first author, year of publication, type of study, study group, type of wedge, number of patients, number surgeries, average patient age, description of cohort, wedge size, and description of surgeries. Abbreviations: AAFD, adult-acquired flatfoot deformity.

Author (Year)	Type of Study	Treatment Group	Type of Wedge	Patients (n)	Feet (n)	Age	Description of Cohort	Wedge Size	Type of Surgery
Ellis (2011)	Retrospective	Group 1 (Metal Wedge)	Metal	13	13	62.5	Patients who underwent flatfoot reconstruction using lateral column lengthening with iliac crest autograft or allograft by the senior author made up of those patients with either a pain level greater or equal to 4 on the visual analog scale or had undergone revision lateral column lengthening	10 mm (max)	Calcaneal osteotomy and/or flexor tendon transfer
		Group 2 (Metal Wedge)	Metal	97	103	61.7	Patients who underwent flatfoot reconstruction using lateral column lengthening with iliac crest autograft or allograft by the senior author including those patients with pain less than 4 on the visual analog scale and no revision surgery	10 mm (max)	Calcaneal osteotomy and/or flexor tendon transfer
Fraser (2019)	Retrospective	Metal Wedge	Titanium	31	32	41.1	Patients all had titanium wedge placement in the medial cuneiform at the time of dorsal opening wedge osteotomy	7 mm	Operative correction for flatfoot deformity with a porous titanium wedge used to correct the forefoot varus component of the multiplanar deformity
Siebert (2021)	Retrospective # (C)	Metal Wedge	Titanium	7	14	60.7	Patients who did not have prior foot surgery on either foot or severe osteopenia as determined by computed tomography attenuation	12 mm (mean)	Lateral column lengthening was performed through an anterior calcaneus osteotomy using a standard sinus tarsi approach

Table 2. *Cont.*

Author (Year)	Type of Study	Treatment Group	Type of Wedge	Patients (n)	Feet (n)	Age	Description of Cohort	Wedge Size	Type of Surgery
Matthews (2018)	Retrospective	Metal Wedge	Titanium	34	43	27.35	Patients who had undergone flexible flatfoot reconstruction using porous titanium wedges within the study period (1 June 2009–30 June 2015)	Evans-size: 8–12 mm, Cotton: 4.5–9.5 mm	Surgical correction of flexible flatfoot deformities using porous titanium wedges
Romeo (2019)	Retrospective	Group 1 (Metal Wedge)	Metal	18	-	36.7	Patients who had Cotton osteotomies and medializing calcaneal osteotomies performed on them by the senior surgeon, and they were randomly allocated into Group 1 (metallic Cotton wedges) and Group 2 (bone allograft)	7.3 mm	Cotton osteotomies and medializing calcaneal osteotomies
		Group 2 (Bone Allograft Wedge)	Bone Allograft	18	-	38.5	Patients who had Cotton osteotomies and medializing calcaneal osteotomies performed on them by the senior surgeon, and they were randomly allocated into Group 1 (metallic Cotton wedges) and Group 2 (bone allograft)	-	Cotton osteotomies and medializing calcaneal osteotomies
Moore (2018)	Retrospective	Metal Wedge	Titanium	30	34	39	All patients had stage II adult-acquired flatfoot deformity and were treated only after initially failing conservative management	Evans-size: 8 mm Cotton: 4.5 and 6 mm	Lateral column lengthening procedure
Gross (2015)	Retrospective	Metal Wedge	Titanium	26	28	46	All patients who underwent lateral column lengthening with a porous titanium wedge at the institution	8 mm	Lateral column lengthening with a porous titanium wedge

Table 2. *Cont.*

Author (Year)	Type of Study	Treatment Group	Type of Wedge	Patients (n)	Feet (n)	Age	Description of Cohort	Wedge Size	Type of Surgery
Stamatos (2023)	Retrospective	Group 1 (Metal Wedge)	Titanium	17	-	47.2	All of the patients had the following criteria: over 18 years of age with at least stage II AAFD, history of flatfoot reconstruction with LCL by one of 3 surgeons in a single practice between October 2008 until October 2018, all causes of adult-acquired flatfoot deformity, and a history of other concomitant accessory procedures including medializing calcaneal osteotomy, excision of accessory navicular, and flexor digitorum longus transfer, among others	-	Flatfoot reconstruction with lateral column lengthening, and the possibility of other concomitant accessory procedures including medializing calcaneal osteotomy, excision of accessory navicular, and flexor digitorum longus transfer, among others
		Group 2 (Bone Allograft)	Bone Allograft	27	-	58.6	All of the patients had the following criteria: over 18 years of age with at least stage II AAFD, history of flatfoot reconstruction with LCL by one of 3 surgeons in a single practice between October 2008 until October 2018, all causes of adult-acquired flatfoot deformity, and a history of other concomitant accessory procedures including medializing calcaneal osteotomy, excision of accessory navicular, and flexor digitorum longus transfer, among others	-	Flatfoot reconstruction with lateral column lengthening, and the possibility of other concomitant accessory procedures including medializing calcaneal osteotomy, excision of accessory navicular, and flexor digitorum longus transfer, among others
Tsai (2019)	Retrospective	Metal Wedge	Titanium	45	48	48.4	All patients with severe flexible pes planovalgus who were treated with corrective osteotomies using trabecular titanium wedges at least 2 years following surgery	-	Corrective osteotomies using trabecular titanium wedges

Table 2. *Cont.*

Author (Year)	Type of Study	Treatment Group	Type of Wedge	Patients (n)	Feet (n)	Age	Description of Cohort	Wedge Size	Type of Surgery
Au (2022)	Retrospective	Metal and Non-Metal Wedges	Both	61	71	44.6	Patients were included if they were older than 13 years of age, had at least 10 weeks of follow-up, and had a diagnosis of either adult acquired flatfoot disorder, tibialis posterior tendon dysfunction, or pes planovalgus. Patients with metal wedges (N = 11) were classified as Group 1, and patients with nonmetal wedges (N = 60) as Group 2	6.83 mm	A Cotton procedure for pes planovalgus
García-Jarabo (2023)	Retrospective	Metal Wedge	Titanium	20	23	63	Patients who had been diagnosed with adult-acquired flatfoot deformity grade IIB, had no previous surgery, and conservative osteoprosthetic treatment with medial support insoles and supinator gradient had failed	8 mm	Lateral column lengthening osteotomy, Cotton osteotomy, and medial sliding osteotomy

Table 3. Information on preoperative and postoperative radiographic outcomes due to wedge utilization in midfoot corrective surgery.

Author (Year)	Treatment Group	Type of Wedge	Patients (n)	Mean Pre-operative Lateral Calcaneal Pitch Angle (°)	Mean Post-operative Lateral Calcaneal Pitch Angle (°)	Mean Preoperative Lateral Talus-First MT Angle (°)/ Meary's Angle (°)	Mean Post-operative Lateral Talus-First MT Angle/Meary's Angle (°)	Mean Preoperative Anterior–Posterior Talonavicular Coverage Angle (°)	Mean Postoperative Anterior–Posterior Talonavicular Coverage Angle (°)	Mean Pre-operative Anterior–Posterior Talus-First MT Angle (°)	Mean Post-operative Anterior–Posterior Talus-First MT Angle (°)	Mean Preoperative Anterior–Posterior Talocalcaneal Angle (°)/ Kite's Angle (°)	Mean Postoperative Anterior–Posterior Talocalcaneal Angle (°)/ Kite's Angle (°)
Ellis (2011)	Group 1 (Metal Wedge)	Metal	13	15.0 (2–30)	-	22.6 (6–45)	-	19.4 (0–46)	-	16.8 (−11–49)	-	-	-
	Group 2 (Metal Wedge)	Metal	97	14.2 (1–24)	-	20.9 (13–36)	-	21.3 (3–55)	-	17.8 (1–29)	-	-	-

Table 3. *Cont.*

Author (Year)	Treatment Group	Type of Wedge	Patients (n)	Mean Preoperative Lateral Calcaneal Pitch Angle (°)	Mean Postoperative Lateral Calcaneal Pitch Angle (°)	Mean Preoperative Lateral Talus-First MT Angle (°)/Meary's Angle (°)	Mean Postoperative Lateral Talus-First MT Angle/Meary's Angle (°)	Mean Preoperative Anterior–Posterior Talonavicular Coverage Angle (°)	Mean Postoperative Anterior–Posterior Talonavicular Coverage Angle (°)	Mean Preoperative Anterior–Posterior Talus-First MT Angle (°)	Mean Postoperative Anterior–Posterior Talus-First MT Angle (°)	Mean Preoperative Anterior–Posterior Talocalcaneal Angle (°)/Kite's Angle (°)	Mean Postoperative Anterior–Posterior Talocalcaneal Angle (°)/Kite's Angle (°)
Romeo (2019)	Group 1 (Metal Wedge)	Metal	18	-	-	9.5 (4.1)	1.4 (1.9)	-	-	-	-	29.5 (4.2)	21.5 (2.5)
	Group 2 (Bone Allograft Wedge)	Bone Allograft	18	-	-	9.8 (4.0)	1.8 (1.7)	-	-	-	-	30.0 (4.0)	21.8 (2.4)
Moore (2018)	Metal Wedge	Titanium	30	-	-	10.9 (5.6)	5.6 (4.9)	37.6 (14.8)	11.0 (14.8)	-	-	-	-
Gross (2015)	Metal Wedge	Titanium	26	13.7 (4.7)	18.9 (5.9)	15.2 (8.6)	8.7 (7.7)	26.4 (9.6)	14.0 (7.2)	21.6 (11.4)	8.8 (7.4)	-	-
Stamatos (2023)	Group 1 (Metal Wedge)	Titanium	17	14.8	22.4	-	-	32.3	8.8	23.1	6.4	-	-
	Group 2 (Bone Allograft)	Bone Allograft	27	12.9	25.4	-	-	26.8	6.9	18.6	5.3	-	-
Tsai (2019)	Metal Wedge	Titanium	45	13.1	18.2	−19.8	−3.9	-	-	-	-	-	-
García-Jarabo (2023)	Metal Wedge	Titanium	20	-	-	15.7 (3.4)	3.1 (2.2)	21.3 (5.4)	7.3 (3.4)	18.3 (5.1)	3.9 (2.4)	-	-

Table 4. Information regarding complications and success rates based on wedge utilization during midfoot corrective surgery. The data recorded include the author, wedge type, number of patients, complications, and success rates.

Author (Year)	Type of Wedge	Patients (n)	Complications	Success Rate (%)
Fraser (2019)	Titanium	31	No complications	100
Matthews (2018)	Titanium	34	No major complications, but there was a 12.6% incidence of minor complications (hardware pain from plates over grafts, 1 case of scar neuritis, and a 5% table incidence of transfer pain associated with the PTWs)	100
Romeo (2019)	Metal	18	One case of malpositioning of the titanium wedge, and one case of HV recurrence	96
	Bone Allograft	18	Three cases of symptomatic bony prominence, one case of osteoarthritis of the first metatarsocuneiform joint, and one case of injury of the terminal branch of the saphenous nerve which required neurectomy	
Moore (2018)	Titanium	30	The overall rate of complications was 20.6%. The most common complications were persistent CC joint pain (14.7%) and peroneal tendonitis (8.8%)	100
Gross (2015)	Titanium	26	-	96
Stamatos (2023)	Titanium	17	Infection (5.9%), pain (11.8%), removal of hardware (11.8%)	100
	Bone Allograft	27	Infection (3.7%), pain (11.1%), removal of hardware (63.0%)	89.9
Tsai (2019)	Titanium	45	There was an overall complication rate of 6.3%	100 (Cotton) 95.8 (Evans)
Au (2022)	Both	61	Complications were manifested by persistent pain at the Cotton surgical site, removal of hardware from the site, subsidence of graft, non-union of the Cotton osteotomy site, anesthesia block complications, and revisions of the medial column. The overall complication rate was 5.6%	97.0
García-Jarabo (2023)	Titanium	20	One case of progression of the deformity requiring double medial arthrodesis and one case of dehiscence of the surgical wound should be highlighted	-

3.6. Complications

Fraser et al. (2019) reported no complications after metallic wedge placement in the medial cuneiform during dorsal opening wedge osteotomy in 31 patients (32 feet) [13]. Matthews et al. (2018) reported no major complications but reported a 12.6% incidence of minor complications (including hardware pain and scar neuritis in 34 patients (43 feet)) with metallic wedge utilization [16]. Romeo et al. (2019) reported one case of metallic wedge misplacement and one case of hindfoot valgus recurrence in the metallic wedge group, whereas there were three cases of symptomatic bony prominence, one case of first metatarsocuneiform joint osteoarthritis, and one case of terminal saphenous nerve injury in the bone allograft group [18]. Overall, Romeo et al. (2019) reported that the utilization of metallic or bone allograft wedges resulted in similarly high patient satisfaction with a comparably low complication rate in their study of 36 patients [18]. Moore et al. (2018) reported an overall complication rate of 20.6%, with persistent joint pain (14.7%) and peroneal tendonitis (8.8%) being the most common complications after lateral column lengthening with metallic wedges in 30 patients (34 feet) [17]. From a total cohort of 44 patients, Stamatos et al. (2023) found that patients treated with a titanium wedge had a 5.9% incidence of infection, 11.8% incidence of pain, and 11.8% incidence of hardware removal as compared to patients treated with autograft/allograft with a 3.7% incidence of infection, 11.1% incidence of pain, and 63.0% incidence of hardware removal [20]. Tsai (2019) reported an overall complication rate of 6.3% in 45 patients (48 feet) treated with corrective osteotomies using trabecular metallic wedges [21]. Au et al. (2022) found an overall complication rate of 5.6% in 61 patients (71 feet) who underwent a Cotton procedure for pes planovalgus using metallic wedges [11]. Complications assessed in the article by Au et al. (2022) included persistent pain at the surgical site, hardware removal, subsidence of graft, non-union, anesthesia block complications, and revisions of the medial column [11]. Garcia-Jarabo et al. (2023) examined 20 patients (23 feet) and had one case of deformity progressing necessitating double medial arthrodesis, as well as one case of dehiscence of the surgical wound with the utilization of metallic wedges [14]. Infection rate reporting was only present in a study by Stamatos et al. [20] (Table 4).

4. Discussion

In this systematic review, the use of metallic wedges for the correction of PCFD conditions was analyzed and described. Information pertaining to radiographic outcomes and union rates, as well as complications, was compiled with the hopes of increasing the reliability of single-institution outcome studies to possibly justify the widespread use of metallic wedges in foot and ankle surgery.

The primary objective of this study was to determine the efficacy of midfoot metallic wedges. Due to outcome measurement heterogeneity, it was difficult to compare similar measurements across studies. However, for seven studies that reported radiographic outcomes, each study showed some improvement [12,14,15,17,18,20,21]. Two of the studies that reported radiographic outcomes included direct comparisons to bone allograft wedges. Of these studies, metallic wedges outperformed bone allografts in 50% and 67% of the reported measurements in each study, respectively [18,20]. Future research on metallic wedges for PCFD correction should include direct comparison to different graft types in order to allow for proper meta-analysis. Radiographic outcomes, however, can be misleading. As correction can be achieved with varying amounts of radiographic improvement (patient specific correction), the analysis of success rates for varying degrees of preoperative conditions would be optimal. For example, PCFD has a classification system to distinguish severity [22]. As this classification system has demonstrated reliability in the literature [23,24], future use of this classification system, rather than traditional radiographic measurements, may better analyze the efficacy of metallic wedges.

Regarding the success rate (as defined in our study as percent union), metallic wedges achieved outstanding results. Of the nine studies that reported, success rates ranged from 95.8–100%. Studies that directly compared the success rates of allograft to metallic wedges found that allografts consistently underperformed metallic wedges with a nearly 10% absolute percent difference (99.3% versus 89.9%). However, this difference may be even larger than the numbers suggest. As the success rate in many studies was not defined as fusion after primary intervention, but rather fusion after any additional necessary intervention, the true success rate of the allograft was much lower. In a study that included a direct comparison of allografts and metallic wedges, allografts required the removal of hardware in 63% of cases, whereas titanium wedges were only removed in 12% of cases [20]. As the reported final allograft success rate was 89.9%, future studies should only be reporting primary fusion rate to avoid misleading data. Furthermore, as revision PCFD correction has demonstrated lower patient-reported outcomes than primary procedures [25], it should be of great interest to investigate and compare wedge materials based solely on their primary procedure success rate.

The secondary aim of this review was to understand the safety and complications of metallic wedges to better inform both patients and physicians of any potential risks. Overall, the complications described in the included studies were all considered minor. Pain at the hardware site, malpositioning of the wedge, persistent pain at surrounding joints, and deformity progression were all noted. The highest complication rate within the included studies was 20.6%, with the most common complications being persistent calcaneocuboid (CC) joint pain and peroneal tendonitis [17]. The authors of this study attribute any CC joint pain to increased joint pressures caused by the graft size, not the graft material [17]. As graft length has been shown to directly correlate with increased CC joint pressures, and in turn increased CC joint pain [26–29], it should be of high priority to implement detailed preoperative planning and wedge manufacturing to tailor the correction hardware to be patient specific. Furthermore, this rate of 20.6% was well within the range found with other common graft materials [30]. One study had concerning infection complications (5.9%) [20]. As previously mentioned, the risk of infection with the use of metallic wedges may be presumed to be reduced compared to allograft wedges, due to metallic elements being less biologically active [6]. Regardless, this rate of infection may indicate a propensity towards biofilm formation, and it requires further investigation to elucidate fully. Finally, it is important to note that complications could be the result of poor surgical technique, rather than the implant material. Using advanced preoperative tools such as three-dimensional distance mapping could prevent technique-related complications [12].

Future trends in the research surrounding metallic wedges should involve long-term prospective comparative studies. A significant impact of metallic wedges relative to allografts may be found within their long-term performance and resistance to subsidence and osseous resorption. As these factors are common for other materials and may lead to a loss of correction [31], the benefit of resorption being highly unlikely due to the composition of metallic wedges is of great interest [7]. However, as resorption tends to be a long-term complication of PCFD correction, the included comparison studies may be limited in understanding the true benefit of metallic wedges given their short follow-up period. Therefore, future comparative studies should include long-term follow-up to further characterize the durability of metallic wedges.

It is important to acknowledge the limitations of this study. As the included articles in this review had high amounts of results' heterogeneity, a proper meta-analysis was not possible. Furthermore, the included articles in this systematic review were observational studies, which clouds the certainty of our results due to inherent bias. Despite these limitations, this systematic review still represents the largest collection of data on the use of metallic wedges for midfoot surgery, which serves both as a foundation for current medical practice as well as a springboard for future research. Additionally, all metallic wedges in this study were assumed to not have much variability in composition. As metallic wedges can differ in terms of porosity, type of metallic element, or surface texture, it is important that future work not only compare metallic wedges to allograft/autograft wedges, but that a proper statistical comparison of metallic wedges with varying composition is included in the analysis. A comparison of porosity may yield interesting results that impact the time to fusion, union rate, and long-term success. To stay within the scope of this review, comparison, beyond the type of metal used, was limited as numerous different design characteristics are available. Future comparisons based on specific characteristics of midfoot wedges would be incredibly informative. Finally, it was impossible to extrapolate from the included studies the severity of PCFD being treated, and therefore this review is not capable of describing how midfoot wedges perform for varying degrees of PCFD severity.

5. Conclusions

This review focused on the efficacy, success rates, and safety of metallic wedges in correcting PCFD deformities. While the results' heterogeneity from the included studies prevented meta-analysis, certain radiographic measurements such as the lateral calcaneal pitch angle and Meary's angle demonstrated greater improvements when using metallic implants compared to allograft wedges. The success rates for metallic wedges were impressive, ranging from 95.8% to 100%, with consistent superiority over allografts. Minor complications like hardware pain and mispositioning were reported, but infection rates remained low due to the inert nature of the metallic elements. Future research should prioritize long-term prospective studies and standardized success rate measures, while acknowledging the need to compare different wedge compositions comprehensively.

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