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Minimally invasive surgery in medial displacement calcaneal osteotomy for acquired flatfoot deformity: a systematic review of the literature

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Abstract

Background Minimally invasive surgery (MIS) in medial displacement calcaneus osteotomy (MDCO) has been proposed for surgical correction of adult-acquired flat foot deformity (AAFD) to reduce complications of open approaches. The aim of our study is to systematically analyze complications and the clinical and radiological results of MIS- MDCO.

Methods A systematic review of the English literature was performed on 30th October 2023. Randomized controlled trials and non-randomized trials, cohort studies, case–control studies and case series concerning surgical correction of AAFD with MIS-MDCO and with at least 15 patients were included. Case reports, technical notes, animal or cadaveric studies were excluded. The quality and risk of bias of the studies included were evaluated using GRADE and MINORS systems. Complications rate, clinical and radiological results were inferred from the studies included.

Results Nine articles were included. A total of 501 cases treated with MIS-MDCO were analysed with a mean follow-up of 11.9 ± 5.1 months. The reported wound infection rate was about 3% and sural neuropathy was rated about 1%. Only 4% of the cases required removal of the screw for pain. In the comparative studies (MIS versus Open MDCO), comparable clinical results but with significant differences ($P < 0.001$) in infection rates (1% versus 14%) and sural neuropathy (2% versus 1%) were observed.

Conclusion AAFD correction performed with MIS-MDCO, with the limitation of a poor quality and high risk of bias of the included studies, seems to provide good clinical results and high subjective satisfaction with a lower complication rate compared to open approach. Further high-quality long-term comparative studies could better clarify complications and clinical and radiological outcomes of the MIS technique in the treatment of AAFD.

Level of evidence Level IV.

Keywords Acquired flat foot · Medial displacement calcaneal osteotomy · Hindfoot correction · Minimally invasive surgery · Results · Complications

Introduction

Adult acquired flat foot deformity (AAFD) is a common and debilitating disease that affects the ligament complex of the hindfoot, particularly the tibialis posterior tendon (TPT), the deltoid ligament and the spring ligament complex. It may cause pain and lead to the collapse of the medial longitudinal arch of the foot. The pathogenesis is still unclear. It is possible to divide the AAFD into 4 stages based on symptoms and deformities [1, 2]. The first-line treatment is a non-surgical approach with non-steroidal anti-inflammatory drugs, orthotics and physical therapy for at least 6 months [3]. If conservative treatment is unsuccessful, especially in stage 4, a surgical approach is indicated [4].

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The surgical treatment for AAFD includes a wide range of procedures; the most common techniques are medial displacement calcaneal osteotomy (MDCO) combined with soft tissue procedures such as flexor digitorum longus (FDL), flexor hallucis longus transfer [5], and lateral column lengthening [6]. The first author to describe calcaneal osteotomy for hindfoot deformity was Gleych in 1893. While the medialisation of the calcaneus was first described in 1971 by Katsougiannis to correct heel valgus that results in overloading along the medial column of the foot [7–9].

The MDCO is performed with a lateral oblique incision to the calcaneus, an oscillating saw for the osteotomy and usually one or two cannulated screws are used for fixation [10–12].

Over the years the lateral oblique incision, first described by Atkins, has been modified to minimise wound-related complications as well as soft tissue, nervous and vascular disorders [10, 13–18]. Classically, iatrogenic damage involves the sural nerve and the peroneal artery [19]. Other frequent complications related to this technique are under-correction of the deformity, non-union, malunion and discomfort caused by the protruding hardware [20].

To reduce these complications, a MIS technique has been proposed [21]. It has been proposed that this approach is safer for soft tissues, allows a lower risk of vascular and nerve structure disruptions, and shorter surgical timing compared to open approaches. Minimally invasive calcaneal osteotomy involves a low-speed, high-torque burr to perform the osteotomy under radiographic guidance [12, 21–24].

The MIS technique aims to improve clinical outcomes and reduce the complication rate associated with traditional approaches. Nevertheless, some studies point to increased exposure to X-rays as an important drawback of this technique [25]. To the best of our knowledge, there has not yet been a systematic review of the current literature on the results and complications of the minimally invasive technique. The hypothesis of the present review is that MIS technique reduces the complications rate compared to traditional open techniques. A systematic review of the literature was performed to analyze the complications and clinical and radiological outcomes of MIS medial displacement calcaneal osteotomy.

Materials and methods

A systematic review of the English literature according to the Cochrane Handbook of Systematic Reviews of Interventions [26] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [27] was performed. A research on the CRD database did not demonstrate previous systematic review on the results and complications of the minimally invasive technique.

An electronic database search was conducted on 30th October 2023: Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE/PubMed, Embase, Scopus, the Science Citation Index Expanded from Web of Science, ScienceDirect. The search was conducted using the keywords: "MDCO", "adult-acquired flat foot deformity", "AAFD", "minimally invasive calcaneal osteotomy", "MIS", "endoscopic calcaneal osteotomy", "percutaneous calcaneus osteotomy", "calcaneal osteotomy", "calcaneal resection", "flatfoot correction", "hindfoot valgus", "posterior tibial tendon dysfunction", "progressive collapsing foot deformity".

Original prospective or retrospective clinical studies reporting complications, clinical and radiological outcomes of patients undergoing surgical correction of AAFD with MIS-MDCO were included. Randomized controlled trials and non-randomized trials, cohort studies, case–control studies and case series with at least 15 patients were considered eligible for this review. Case reports, technical notes, abstracts, editorial commentaries, ex vivo, pre-clinical studies (on animal or cadaveric models) and clinical studies without an adequate study population were excluded from the analysis.

For the initial screening, 1847 studies were identified. After removal of duplicates, articles were evaluated for relevance based on the title and abstract. The selected articles were then assessed using pre-defined inclusion and exclusion criteria. The reference section of the identified articles was checked for omission of other relevant articles.

The level of evidence of included studies was assessed through the adjusted Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence [28]. The quality of studies was defined using the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) system [29]. The GRADE system classifies the quality of evidence in one of four levels (high, moderate, low, and very low) evaluating study limitations, inconsistency of results, indirectness of evidence, imprecision, and reporting bias.

The risk of bias in the included studies was classified using the Methodological Index for Non-Randomized Studies (MINORS) [30]. A critical analysis of the funding sources of the included studies was also performed.

The MINORS contained 12 items, the first eight are in common for comparative and non-comparative studies, and four additional criteria are specific for comparative studies. Each MINORS item was given a score of 0 when absent, 1 when present but inadequate, and 2 when present and adequate. Therefore, the ideal score for comparative studies was 24 and for non-comparative studies was 16. Comparative studies were classified as being at high risk of bias if the overall score was ≤ 20, and at low risk of bias with a score > 20. Non-comparative studies were considered at high risk of bias when the overall score was ≤ 12 and at low risk of bias with a score > 12.

When available, the following data were obtained from the articles: first author, year of publication, country, study design, number of patients (divided by groups in case of controlled studies), number of procedures, type of intervention, side, mean age of patients (years), gender and mean follow-up (months). Studies that did not report a specific variable were excluded from the overall assessment of this variable. The main outcome considered was the complications; secondarily we analyzed clinical and radiological results and the hospital length of stay. Categorical data were expressed as number of cases or percentage. Continuous variables were referred as mean and standard deviation. Analyzing the comparative studies (MIS versus Open MDCO), a comparison between the different groups concerning clinical outcomes and the incidence complications was performed using the median Kruskal–Wallis test (all groups confounded). Two-sided p values were reported, and significance was accepted at $p < 0.05$.

Results

Nine studies were eventually included: three papers were retrospective comparative studies between open and MIS techniques [12, 25, 31], while the remaining studies were retrospective case series on MIS-MDCO [15, 17, 22, 32–34]. The PRISMA diagram illustrates the identified, included and excluded studies, as well as the rationale for exclusion (Fig. 1).

Six studies were LOE IV [15, 17, 22, 32–34] and three were LOE III [12, 25, 31]. The overall quality of the included studies was extremely low according to the GRADE system (Table 1) and, at the same time, the risks of bias were high according to the MINORS criteria. Eight of the included studies [15; 17; 22; 25; 31–34] reported not having any significant financial support for their research; in one study [12] the authors reported financial support from industry (Supplementary Table 1).

Pooling the data, 501 MIS MDCO procedures with a mean follow-up of 11.9 ± 5.1 months (range 3–66) were included. Two hundred sixty-nine patients (65%) were women, and one hundred forty-three (35%) were men. The mean age was 49.1 ± 6.9 (range 12–87) years. In the three comparative studies [12, 25, 31], a total of 141 open MDCO procedures were reported. Table 2 reports the demographic data of the included studies.

The MIS technique was performed in the lateral position in five studies [12, 15, 22, 31, 32] and in the supine position in four studies [17, 25, 33, 34]; the entry point was in the safe zone for the sural nerve at the highest point of the posterior tuberosity of the calcaneus immediately anterior to the insertion of the Achilles tendon and guided with fluoroscopy. All authors performed the osteotomy with Shannon burr, except Velijkovic et al. [17] and Coleman et al. [33] who performed the osteotomy with a Gigli saw under endoscopic assistance and with a microsagittal saw, respectively.

Translation fixation was performed with a single 6.5 cannulated screws or two 4.3 cannulated screws, only Coleman et al. [33] used a lateral plate in some cases.

Several outcome measures, such as the American Orthopedic Foot and Ankle Score, Visual Analogue Scale, Short Form Health Survey 36, and numeric rating scale, were used to assess the clinical outcome.

The mean pre- and post-operative AOFAS were 51 ± 11.8 (range 42–71) and 89.6 ± 8.7 (range 77–100) respectively.

The overall complications rate in MIS-MDCO was 7.7 ± 6.8%. The wound infection rate was 3.0 ± 6.5%, the sural neuropathy rate of 0.9 ± 2.1%. In 5.1 ± 5.2% of cases, screw removal was reported for pain. The medial displacement was 8.35 ± 1.18 mm (4–15). Two studies reported non-union [12, 33].

Four studies [22, 31, 33, 34] assessed demographic information such as age, gender, race, BMI, American Society of Anesthesiologists (ASA) classification and comorbidities such as diabetes mellitus, immunodeficiency, chronic kidney disease, peripheral neuropathy, congestive heart failure, peripheral vascular disease, tobacco use (never smoker, former smoker, current smoker).

Wound dehiscence and sural neuropathy were not significantly associated with any demographic variable or comorbidity in all the studies. Coleman et al. [33] found an association between complications of osteotomy healing and ASA classification, female gender, current tobacco uses and higher body mass index. Five of the included studies [12, 25, 32, 33] described the post-operative rehabilitation protocol. The comparative studies by Kendal et al. [12] and Waizy et al. [25] applied the same protocol to both MIS- and open-treated patient groups. In most cases, the authors suggested a below-knee cast for 12 weeks and weight-bearing was prohibited for 4 to 6 weeks.

Analysing the comparative studies (MIS versus Open MDCO), no statistically significant differences in AOFAS score at last follow-up were found between patients treated with open and mini-invasive procedures ($P > 0.001$). Nevertheless, significant differences were found in the rate of wound infection (14% open-MDCO versus 1% in MIS-MDCO) and the rate of sural neuropathy (11% open-MDCO versus 2% in MIS-MDCO) ($P < 0.001$). Table 3 reports complications data of the included studies.

Three studies [12, 25, 31] described hospitalization of 3.2 ± 1.3 (0–7) days, significantly lower than the reported in the open group of the comparative studies, 6.2 ± 1.3 (2–16) days ($P < 0.001$).

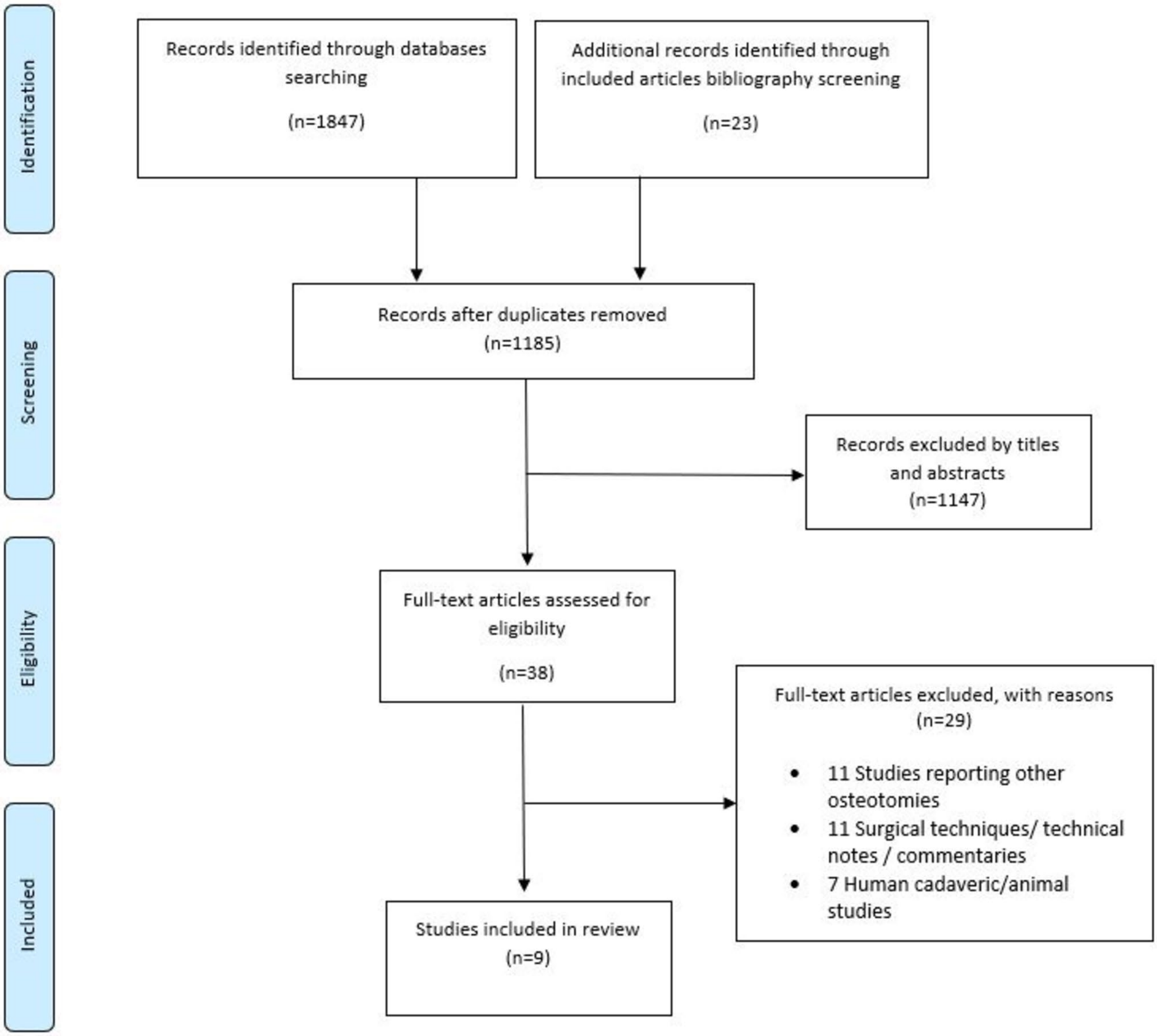

Fig. 1 PRISMA flowchart

Table 1 The evaluation of quality of the included studies according Grading of Recommendations, Assessment, Development and Evaluations (GRADE) system

	Apriori GRADE	Risk of bias	Inconsistency of Results	Indirectness of evidence	Imprecision	Reporting Bias	Final GRADE
Kendal et al. [12]	low	Y	N	N	N	N	Very Low
Jowett et al. [16]	low	Y	N	N	N	N	Very Low
Veljkovic et al. [17]	low	Y	N	N	Y	N	Very Low
Kheir et al. [22]	low	Y	N	N	Y	N	Very Low
Waizy et al. [25]	low	Y	N	N	N	N	Very Low
Gutteck et al. [31]	low	Y	N	N	N	N	Very Low
Catani et al. [32]	low	Y	N	N	Y	N	Very Low
Coleman et al. [33]	low	Y	N	N	N	N	Very Low
deMeireles et al [34]	low	Y	N	N	N	N	Very Low

Table 2 Included studies

Main author	Country	Study design	LOE	GRADE	MINORS	Number of patients	Number of procedures	Type of intervention	Mean age	Sex	Mean Follow-up (months)
Kendal et al. 2015 [12]	UK	Comparative study	III	very low	17	81	81 (50 Open /31 MIS)	Open vs MIS MDCO	47.7 (16–77)	58F; 23 M	minimum 3
Jowett et al. 2015 [15]	AUS, SCO	Retrospective Case series	IV	very low	12	35	35	MIS MDCO	59 (16–75)	/	23 (6–36)
Veljkovic et al. 2019 [17]	USA	Retrospective Case series	IV	very low	11	41	41	MIS MDCO with Endoscopical assistance	41.1 (18–68)	21F; 20 M	6
Kheir et al. 2015 [22]	UK	Retrospective Case series	IV	very low	12	29	29	MIS MDCO	54 (37–72)	24 F; 5 M	6
Waizy et al. 2018 [25]	GER, UK	Comparative Study	III	very low	17	82	82 (33 Open /27 MIS)	Open vs MIS MDCO	45 (14–69)	36F; 24 M	minimum 3
Gutteck et al. 2019 [31]	GER	Comparative Study	III	very low	17	122	122 (58 Open /64 MIS)	Open vs MIS MDCO	62 (12–78)	78F; 44 M	12
Catani et al. 2021 [32]	ITA	Retrospective Case series	IV	very low	11	20	20	MIS MDCO	46.6 (41–52)	13F; 7 M	12
Coleman et al. 2021 [33]	USA	Retrospective Case series	IV	very low	10	160	189	MIS MDCO	42 (10–81)	123F; 66 M	12 (3–66)
deMeireles et al. 2022 [34]	USA	Retrospective Case series	IV	very low	11	65	65	MIS MDCO	46.2 (13–87)	/	minimum 12

Table 3 Complications and hospitalization time

		Hospitalization time (days)	Wound infection rate (%)	Sural neuropathy rate (%)	Non-union rate (%)	Screw removal rate (%)	Overall complications rate (%)
Kendal et al. [12]	MIS	3.8 (2–7)	3.2	0	3.2	12.9	19.4
	Open	4.3 (2–15)	20.0	6.0	0	5.0	36.0
Jowett et al. [16]	MIS	/	0	0	0	11.4	11.4
Veljkovic et al. [17]	MIS	/	0	0	0	9.8	9.8
Kheir et al. [22]	MIS	low	0	0	0	3.4	3.4
Waizy et al. [25]	MIS	4 (1–6)	0	0	0	0	0
	Open	7 (4–16)	3	9.1	0	0	12.1
Gutteck et al. [31]	MIS	4 (1–6)	0	6.3	0	6.3	12.5
	Open	7 (4–16)	15.5	13.8	0	8.6	37.9
Catani et al. [32]	MIS	/	0	0	0	0	0
Coleman et al. [33]	MIS	/	2.6	2.1	4.8	2.1	11.6
de Meireles et al. [34]	MIS	/	1.5	0	0	0	1.5

/: not reported

Discussion

MIS-MDCO, with the limitation of poor-quality and high risk of bias of the included studies, seems to be an effective technique for the correction of AAFD, as demonstrated by the low complication rate, good clinical and radiological outcomes. The present review includes international studies on MIS-MDCO. The analysis of funding sources of the included articles demonstrates only one study with financial support from industry. Concerning complications as primary outcome of analysis, the MIS approach demonstrates an overall complications rate of 7.7% versus 28.7% of open approach. The hypothesis of the present review is then confirmed.

Comparative studies by Kendal et al. [12], Waizy et al. [25], and Gutteck et al. [31] showed no significant differences in clinical outcome scores, radiological union and operative timing; however, these studies observed a numerically lower rate of complications and shorter hospitalization in patients treated with MIS techniques. The wound infection rate was 14% in the open group versus 1% in the MIS group. Similarly, the rate of sural neuropathy was 11% in the open group and 2% in the MIS group. It should be noted that all the included comparative studies had small sample sizes, which limited their statistical power. Nevertheless, previous studies on the open lateral approach have reported similar complication rates, with wound complications occurring in 5–10% of patients and sural nerve damage occurring in 7–25% of patients [13, 14, 35–38].

According to the literature, the sural nerve and perforating peroneal vessels are the main risks during open lateral surgical approaches to the calcaneus [9, 15, 35]. Cadaveric analysis has shown that the distance to the sural nerve is 7 mm from the malleolus, making surgical access safe for MIS [15], a finding confirmed by the low sural complication rate observed in all the included studies.

Most of the included studies reported a high union rate of calcaneal osteotomies. However, Coleman et al. [33] observed a statistical correlation between biological risk factors as ASA classification, female gender, current tobacco uses and higher body mass index and osteotomy healing complications after minimally invasive MDCO procedures. This same correlation has previously been described in studies on the management of pseudarthrosis. [39].

These patient features and comorbidities have also been reported as risk factors for increased complications rates in hindfoot trauma surgery and open-MDCO [40–43].

The data extrapolated in this review seem to suggest no correlation between the previously reported risk factors and the most frequent complications, such as wound infection and sural neuropathy. Furthermore, when analyzing comparative studies included in this review, a significant reduction in complications rate in the MIS group compared to the traditional open approach can be seen. Gutteck et al. [31] found that 9 patients (15.5%) with open calcaneus osteotomy had wound healing problems, seven of whom suffered from diabetes and five were smokers. In the percutaneous group, on the other hand, no wound healing complications occurred, despite the higher percentage of smokers and patients with diabetes. The reduction in wound dehiscence in MIS approach could be explained by less surgical damage to the soft tissue, the non-use of tourniquets and distractors and the use of abundant irrigation during osteotomy that reduces heat damage of the soft tissue and infection risk. Reddy et al. [44] demonstrated in a cadaver study that cold irrigation can even potentially reduce the risk of osteotomy non-union.

It should be noted that most of the studies included patients who underwent secondary procedures in addition to medializing osteotomy of the calcaneus; this may bias the post-operative assessment and surgical timing. In any case, no significant differences in operating timing or X-ray exposure were found in comparative studies [25]. Interestingly, concomitant procedures, including adjacent fusions, did not affect the rate of osteotomy healing complications. Furthermore, the total number of concomitant procedures did not influence the rate of bone union. This finding should reassure the surgeon in performing multiple concomitant procedures to correct very complex deformity [34].

In the included studies, the authors used both the Shannon Burr and a Gigli Saw. For fixation, similar functional results were found using one or two leg screws and a plate, but screws are certainly cheaper and less invasive than plates. Similar functional results can be observed in open MDCO procedures with screws or lateral plates, but a higher rate of osteotomy healing is observed with screws (100%) than with plate fixation (94%) [45].

Coleman et al. [33] observed a high rate of osteotomy healing complications, all in patients undergoing the minimally invasive burr technique with lateral plate fixation at 12 months.

No studies analyzing the use of K-wires as fixation for MIS MDCO were found in the literature, but it could be an interesting alternative to reduce hardware complications in the future. Moses Lee et al. [46] described the use of k-wires as an accurate guide for MIS osteotomy, shortening the learning curve and increasing accuracy of osteotomy.

Conclusion

This systematic review of the literature demonstrates that AAFD correction performed with MIS-MDCO seems to provide good clinical outcomes with a lower complication rate and shorter hospitalization than open-MDCO. We can, therefore, conclude that the minimally invasive technique could be a viable alternative to traditional open techniques for AAFD correction and should be considered as the gold standard for patients with a high risk of poor soft tissue healing due to diabetes and other comorbidities. Further high-quality long-term comparative studies could better clarify the complications and the clinical and radiological outcomes of the MIS technique in AAFD treatment.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent This article does not contain any studies with human participants or animals performed by any of the authors.

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