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The Effectiveness of Surgical Interventions in the Management of Malunited Calcaneal Fractures: A Systematic Review

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ABSTRACT

Nonoperative management may result in calcaneal malunion with consequences of pain, deformity, and functional limitation. The aim of this review was to proffer an evidence-based scientific account of the effectiveness of contemporary surgical procedures in the management of malunited calcaneal fractures after initial conservative management. This systematic review included studies that evaluated the surgical procedures in the management of calcaneal malunion and systematically searched studies published between January 2005 and June 2016. The search was conducted using the following search engines: the Cochrane Library, Web of Science, PubMed/ MEDLINE, EMBASE, CINAHL, Academic Search Premier, and Open Grey. Methodologic assessment was conducted using the Cochrane Risk of Bias In nonrandomized Studies- of Interventions assessment tool version 7. Ten observational studies (212 patients) were included in this review. Five articles explored various means of achieving subtalar arthrodesis, 2 articles evaluated joint-sparing osteotomies, 1 examined corrective osteotomy for extra-articular os calcis malunion, and 2 articles explored combined procedures based on the Stephen and Sanders calcaneal malunion classification. Clinical and methodologic heterogeneity did not allow quantitative pooling of results. The overall risk of bias was considered moderate in 7 studies and 3 were considered at high risk of bias. The inability for any study to be considered at low risk of bias in this review might be mainly attributed to the lack of a valid and reliable outcome measure for the assessment of foot and ankle conditions. There is clear evidence that appropriately indicated procedures are effective in terms of pain alleviation, correction of deformity, and improved function. However, long-term outcomes may improve the acceptability to joint-preserving osteotomies, subtalar arthrodesis with the VIRA implant and subtalar distraction osteogenesis.

The calcaneus or os calcis is the largest and most frequently fractured tarsal bone, representing 60% of tarsal bone fractures (1). The annual incidence of calcaneal fractures in the United Kingdom in 2009 was 11.5 per 100,000 population (2). These fractures account for 2% of all fractures (3), and 40% of these fractures are fraught with complications including calcaneal malunion (CM) (2,4).

CM, which is one of the late sequela of calcaneal fractures, and refers to residual bony malalignment frequently associated with pain and deformity resulting from inadequate conservative or inadequate/failed surgical treatment (5,6). CM can be intra-articular and involving subtalar joint, or extra-articular, which spares the subtalar joint (7,8). CM is mostly thought to be a complication of intra-articular fractures, where about 75% of calcaneal fractures are intra-articular (9,10), although CM has also been reported as a consequence of extra-articular fractures (11,12). The management of calcaneal fractures and their sequelae constitute a challenge to clinicians and researchers, and it remains a debatable topic in the literature (13–15). Calcaneal fractures and their complications, particularly CM, constitute a significant socioeconomic burden, where victims can be incapacitated for several years, in addition to the large budget spent per patient (16–18). Therefore, robust evidence-based knowledge of the optimal management of calcaneal pathologies particularly CM could be of considerable benefit to both patients and health care systems.

Recently, in a randomized controlled trial conducted across 22 hospitals and 27 specialist surgeons in the United Kingdom National Health Service, Griffin et al (19) compared the outcomes of operative and

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nonoperative management of os calcis fractures. The subjective and objective outcome measures used demonstrated that surgical treatment showed no clinical or functional benefit after 2 years and the risk of complications as well as reoperation rate was higher in the operated group. These researchers concluded that operative management is not advocated for the management of displaced intra-articular calcaneal fractures, unless they are severely displaced.

In assessing the surgical option, a number of researchers have endeavored to appraise the different surgical procedures that seek to alleviate the symptoms and correct the deformities associated with CM (8,20,21). Rammelt et al (20) conducted a prospective study to assess foot function after subtalar bone block arthrodesis in 31 patients with unilateral CM. Clinical and biomechanical foot functions were assessed using the American Orthopaedic Foot and Ankle Society (AOFAS) score and dynamic pedobarography, respectively, before and after the procedure. This procedure has revealed a considerable improvement in the hindfoot score, talar declination angle, and talocalcaneal height, suggestive of decreased pain and better foot function as a result of improvement in foot alignment. Dynamic pedobarography also reflected a return to normal pressure distribution of the foot and better gait. More recently, Rammelt et al (22) recorded similar mid- to long-term improvement in 5 patients who were managed with joint-sparing corrective osteotomy and soft tissue procedures for intra-articular CMs.

An up-to-date systematic review examining the procedures used for the surgical management of CM, to the author's best knowledge, is unavailable within the existing body of literature. Although there was a systematic review conducted by Schepers (23) on subtalar distraction block arthrodesis for CM, a survival analysis of systematic reviews of randomized, controlled trials revealed that significant new evidence become available for 23% of articles reviewed within 2 years (24). For these reasons, such a review may provide essential evidence-based data to inform management guidelines used to advise clinicians and other health care providers. This systematic review focuses on studies that have examined the effectiveness of contemporary surgical procedures in the management of CM to evaluate the clinical and functional outcomes after these interventions.

Materials and Methods

Calcaneal fractures and their sequelae predominantly occur among young males (3); hence, studies that had participants older than 16 years were selected. This selection criterion was also supported by the fact that operative management of calcaneal injuries should be undertaken in patients who have reached skeletal maturity (25). Furthermore, outcomes of recent studies that showed that skeletal age tends to be 2 years greater than chronological age in adolescents (26).

CM is widely believed to be a result of conservative management of calcaneal fractures or inadequate reduction (20). Consequently, studies that included participants with an established diagnosis of CM who had been managed conservatively or with closed reduction for os calcis fractures were included, whereas previous open reduction and internal fixation to the ankle and foot was a criterion for exclusion. This rule was to ensure preservation of the native anatomy and reduce chances of infection (27,28), because a further alteration in anatomy and biomechanics could be sources of confounding variables, which could yield suboptimal clinical and functional outcomes when unstandardized surgeries are performed (29). Additionally, and to minimize other potential confounding factors, exclusion criteria included arthroscopic procedures, which may not be effective for the correction of severe deformities (30), and patients who had rheumatoid arthritis or any neurologic problems, which might inhibit walking (31). Finally, participants in the selected studies must have been followed up for at least 1 year, because such a length of time may be required to fully assess the residual deformity associated with calcaneal injuries (32). This in line with the fact that sufficient time for rehabilitation as well as bone remodeling is required to achieve as close to the preinjury levels as possible (9,11,19). It has been also shown that a prolonged rehabilitation period is needed in calcaneal injuries (a minimum of 1 year) in 20% of patients (33), probably owing to the spongy or trabecular nature of the os calcis, which makes it weaker and more prone to fractures than cortical bone (34,35). The selection criteria and search strategy flow chart for this review are illustrated in Table 1 and the Fig, respectively.

Table 1
Selection criteria used by the systematic review

Inclusion Criteria	Exclusion Criteria
Articles published between January 2005 and June 2016	Studies published before 2005
Surgical procedures treating calcaneal malunion	Arthroscopic procedures
Initial conservative management or closed reduction	Initial open reduction and internal fixation to the ankle and foot
Minimum follow-up period of 1 year	Patients with rheumatoid arthritis
Involving humans above 16 years old	Patients with neurologic disorders
Published in English	Studies not published in English

The Cochrane Risk of Bias In Non-randomized Studies of Interventions assessment tool version 7 was used in the critical appraisal of the included studies. This tool is based on the validated Cochrane Risk of Bias tool for randomized trials, which evaluates the risk of bias during the preintervention, intervention, and postintervention phases (36). Each study was appraised by a primary author in addition to an independent reviewer to achieve a consensus, thereby enhancing methodologic rigor in this review. Moreover, and owing to the peculiarities of nonrandomized studies, it has been recommended that a study appraisal should be conducted by at least 2 raters to reach a consensus (36).

Results

There were 212 participants with 235 feet who were included in these 10 observational studies. The majority of the participants were males (80%). The youngest and oldest participants were 16 and 74 years old, respectively (Table 3). The assessment for risk of bias of all included studies (divided into groups A, B, and C) is illustrated in Table 2.

All studies have used the AOFAS hind foot score. Two studies applied the Maryland Foot Score (37,38). The Medical Outcome Short Form (SF-36) was used in 1 study (37). It should be noted that several flaws with the AOFAS rating scale were revealed recently in the literature; hence, there is a need to combine the score with other subjective and objective outcome measures until a validated and more encompassing foot and ankle outcome tool is developed (39,40). One of the flaws with the AOFAS rating scale is that the degree of change that represents a significant clinical change is not known (40). Second, the AOFAS score itself seems to lay emphasis on pain to the detriment of other symptoms, which may skew the scores, thereby reducing the validity where conditions of deformity or range of motion are of overriding concern (40,41). For these reasons, the hitherto partially validated AOFAS score has since come under worse scrutiny and is no longer recommended as the outcome tool of choice for foot and ankle conditions (39,40), and its doubtful validity and reliability have urged some authors to discontinue its use (40).

Therefore, prior research that used the AOFAS score and scores akin to it such as Maryland Foot Score should be interpreted with caution. Although the SF-36 is validated, it is a nonspecific for foot and ankle conditions (42). For this reason, it is advocated that the SF-36 should be combined with a more specific tool in the evaluation of foot and ankle pathologies (43).

Discussion

To enable a clearer comparison between the included studies, these have been divided into groups A, B, and C. In group A, 5 studies focused on different procedures to achieve a subtalar arthrodesis in varied clinical scenarios (38,44–47). Studies in group B addressed joint-sparing and corrective osteotomies (11,22,48). In group C, 2 studies investigated the combined procedures in the surgical treatment of CM based on the Stephens and Sanders classification (37,49).

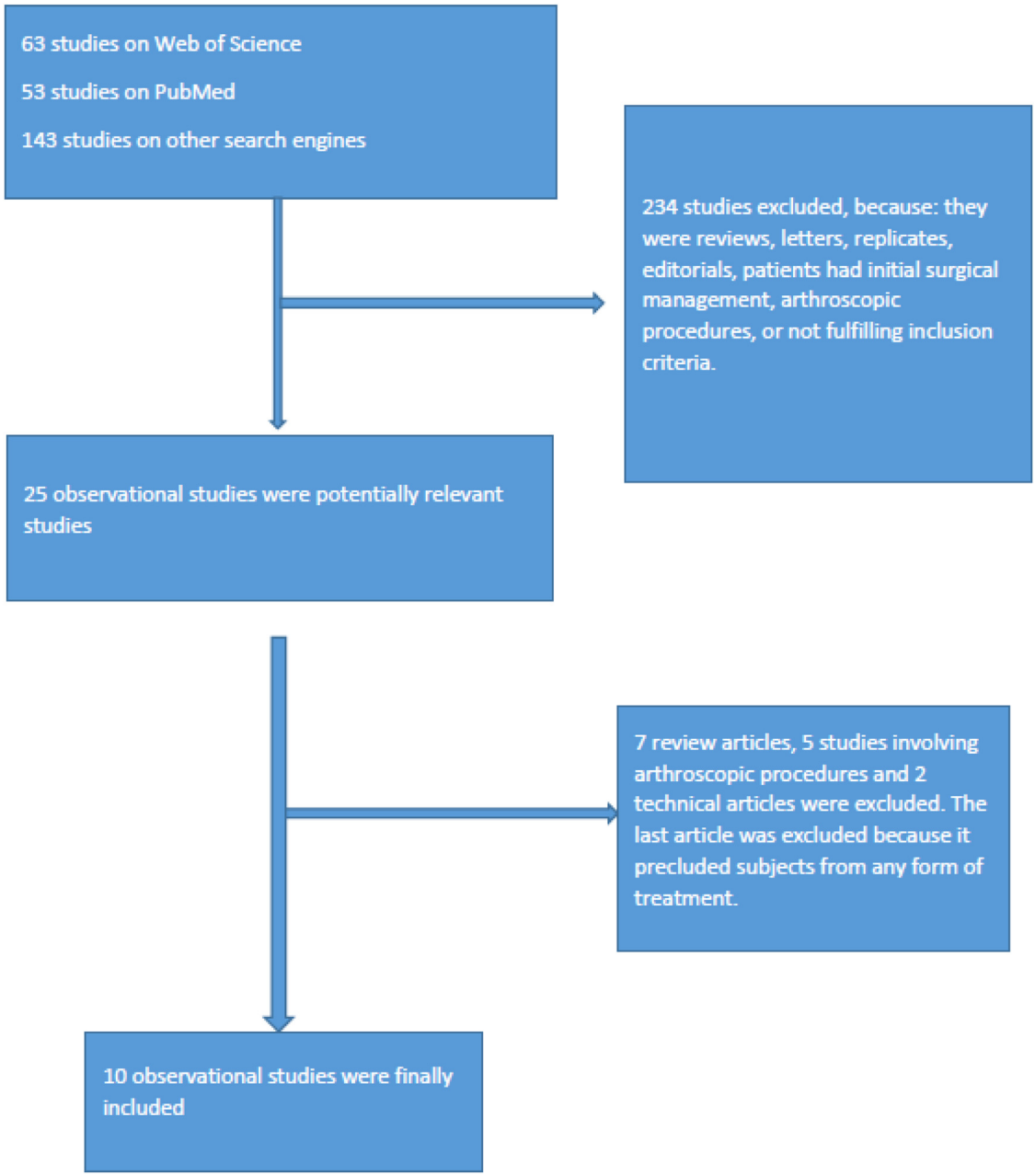

Fig. Search strategy flow chart.

Outcomes of Included Studies

Group A

Isolated subtalar arthrodesis was performed in the study conducted by Yavuz et al (47). The title of the study, which referred to conservatively managed os calcis fractures as "neglected," seemed misleading. The outcomes expected would have been worse if the fractures were indeed neglected. Yavuz et al (47) recorded significant difference in preoperative and postoperative AOFAS score for patients treated with isolated subtalar fusion. However, there was no difference between the radiologic measurements, namely the talocalcaneal angle, talar declination angle, and talocalcaneal height. There was also no difference between fusion time regardless of bone grafting, and this might be due to difficulty in obtaining radiologic assessments postoperatively while patients had short-leg casts, which could be a possible confounder. Second, the talocalcaneal angle, which could be anterior or lateral, was not specified (50,51). Furthermore, there is a wide range of values for the lateral talocalcaneal angle in the literature between 15° and 60° (51). Thus, it has been suggested that, for unilateral injuries, the reference should be taken as the value for the contralateral limb. Yavuz et al (2014) (47) did not state the method applied in the determination of radiologic evaluation, or if the contralateral values were applied as references for patients with unilateral injuries. It is not known if these reasons might explain the nonsignificance of radiologic measurements obtained. Nonetheless, Yavuz et al (47) observed a 95% union rate in their study. Of 20 patients, only 2 developed asymptomatic midtarsal joint arthritis (52) and only 1 patient had a change of job.

Radnay et al (38) was the only study in this review that had an outcome data retrieval process done by a blinded research nurse, which might have decreased the potential for detection bias. Although the

Table 2
Assessment for risk of bias in included studies

	Group A					Group B			Group C	
Bias	El-Soufy (44)	López-Oliva et al (45)	Radnay et al (38)	Fan et al (46)	Yavuz et al (47)	Aly (11)	Rammelt et al (22)	Yu et al (48)	Al-Ashhab (49)	Clare et al (37)
Confounding	Moderate	High	Moderate	No information	Moderate	Moderate	Moderate	Moderate	Moderate	High
Selection	Low	Moderate	Low	Moderate	Low	Low	Moderate	Low	Low	Low
Classification of interventions	Low	Moderate	Low	Low	Low	Low	Low	Low	Low	Low
Deviations from intended intervention	Low	Low	Low	Low	Low	Low	No information	Low	No information	No information
Missing data	Low	Low	High	Low	Low	Low	Low	Low	Moderate	High
Measurement of outcomes	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Selection of reported results	Moderate	Low	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Low
Overall	Moderate	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High

AOFAS score improved for the conservative group managed with subtalar distraction arthrodesis, the score was found to be significantly higher for the surgical group, which underwent in situ subtalar fusion. Conversely, subsequent research showed that, irrespective of the type of arthrodesis used, no statistically significant difference was recorded in Maryland Foot Score, SF-36, or visual analogue scale scores whether patients had initial conservative or surgical treatment (53). With the recent invalidation of the AOFAS score (40), all studies in the literature that have used this outcome score and studies akin to it now seem questionable. Moreover, no data regarding the radiologic assessment in this study were given, which necessitates that the results of this study should be interpreted with caution.

El-Soufy (44) recorded a considerable increase of more than 50 points on the AOFAS score at final follow-up and a mean increase of 7 mm in talocalcaneal height was recorded postoperatively and 6 mm at final follow-up. The loss of 1 mm at final follow-up might be attributed to consolidation of the subtalar distraction bone–block fusion (54). Increases in talar declination and calcaneal inclination angles also corroborate the increase in talocalcaneal height with subsequent resolution of impingement, which translates to pain relief and markedly improved scores on the AOFAS scale. Despite nonuse of screws or staples for bone graft fixation in the El-Soufy study (44), solid fusion achieved at a mean of 20 weeks in this study, and this finding might be attributed to adequate cartilage removal, and appropriate use of cancellous and corticocancellous bone autografts, which increase bone contact surface area thereby preventing nonunion (54). Subtalar bone block arthrodesis was proven to be an effective modality for treating CM in the El-Soufy study (44), with 80% of patients returning to preinjury occupations, and 90% recorded markedly decreased pain, much improved function, and longer walking distances.

López-Oliva et al (45) explored minimally invasive surgery using the VIRA implant for subtalar arthrodesis with 91% union rate in 27 cases of CM. At a mean follow-up of 1.5 years, there was significant increase in AOFAS score from 42.1 to 71.6 as well as considerable improvement in Bohler's angle. This technique seems to improve construct of the surgery enabling early rehabilitation and shorter hospitalization thereby reducing the possibility of ankle stiffness (55). However, and apart from the conflict of interests in the López-Oliva et al study (45), long-term results are required, so the adoption of this method can be considered by health care providers. Nonetheless, the VIRA implant seems a feasible alternative in the fixation methods for subtalar arthrodesis .

Fan et al (46) used subtalar distraction osteogenesis with external fixators to achieve arthrodesis. This novel approach achieved considerable success, with 6 of 8 feet recording an 87% increase in talocalcaneal height when compared with the contralateral limb. The single patient with bilateral severely collapsed calcaneal fracture also recorded increases of 14.5 and 13.4 mm for the left and right foot, respectively. However, the benefits of subtalar distraction osteogenesis must be weighed for individuals with an increased risk of deep vein thrombosis owing to the long period of decreased mobility while the lengthening device remains in place. Precautions also have to be taken to prevent pin tract infection, because the untoward occurrence of osteomyelitis can result in disastrous consequences (29,56). Moreover, there might be a need to improve the external fixators used in this procedure to prevent the possibility of injury to the ankle joint while distracting the subtalar joint (57). Although a larger sample size and longer term follow-up are still needed, subtalar distraction osteogenesis seems to be a viable alternative to managing patients with severely collapsed calcanei in the near future.

Group B

Aly (11) observed a 91% success rate in the correction of valgus deformities of extra-articular malunion with the lateral opening wedge osteotomy. The lateral column lengthening osteotomy, which corrected

Table 3
Demographic data of included studies

Study	Focus of Study	No. of Patients and Feet	Mean Age (y)	Male, no. (%)	Mechanism of Injury and Percentages	Mean Time From Injury to Surgery (mo)	Mean Follow-Up Period (y)
Clare et al (37)	Combined procedures based on Stephen and Sanders CM classification	40 patients (45 feet)	46.8	31 (77.5%)	Not declared	16.4	5.3
Radnay et al (38)	Subtalar fusion	35 patients (39 feet)	46.4	25 (71.4%)	Fall from height (74%) MVA (26%)	16.4	5.3
López-Oliva et al (45)	Subtalar arthrodesis	23 patients (27 feet)	47	23 (100%)	Not declared	22	1.5
Aly (11)	Corrective osteotomy	28 patients (34 feet)	34.7	24 (86%)	Fall from height (82%) MVA (18%)	28	4.7
El-Soufy (44)	Subtalar distraction bone-block fusion	20 patients (20 feet)	30	15 (75%)	Fall from height (70%) MVA (30%)	Not declared Range; 8 to 12	2
Yu et al (48)	Joint-sparing osteotomy	24 patients (26 feet)	32.6	21 (87.5%)	Fall from height (54%) Fall from stairs (8%) MVA (30%) Exercise (8%)	5.7	2.9
Al-Ashhab (49)	Combined procedures based on Stephen and Sanders CM classification	11 patients (11 feet)	28.7	11 (100%)	Fall from height (100%)	16.2	1.1
Yavuz et al (47)	Subtalar fusion	20 patients (21 feet)	44.3	16 (80%)	Not declared	30	3.6
Fan et al (46)	Subtalar distraction osteogenesis	7 patients (8 feet)	29.4	3 (43%)	Fall from height (100%)	Not declared Range 4 to 18	1.2
Rammelt et al (47)	Joint-sparing osteotomy	4 patients (4 feet)	45.3	0 (0%)	Not declared	3.25	2.6

Abbreviations: CM, calcaneal malunion; MVA, motor vehicle accident.

Table 4
Detailed results of group A studies

Study	Procedures Outcome Measures	Results	Strengths and Limitations
El-Soufy (44)	Subtalar distraction bone block fusion without screws and staples AOFAS	At mean follow-up of 2 years, all 20 patients showed solid fusion at a mean of 20 weeks. AOFAS score increased from a mean of 22.0 preoperatively to 75.7 postoperatively. Although 90% of patients recorded less pain, 10% observed no change. Pain intensity decreased by 70% on the average. There were 16 patients who returned to preinjury occupation and 4 assumed lighter working conditions. The talocalcaneal angle increased from a mean of 22.0 to 27.2°. Value at final follow-up was 26.2°. The calcaneal inclination angle increased from a mean of 5.2° to 8.6°. The value at final follow-up was 8°. Talar declination angle increased from 6.2° to 25°. The value at final follow-up was 24.2°. The talocalcaneal height increased from a mean of 65.2 to 72.6 mm. The value at final follow-up was 71 mm.	Description of study could aid reproducibility. No drop out of subjects from the study eliminating the potential for attrition bias. No conflicts of interest. Small sample size. Lack of power calculation to determine adequate sample size. Designation and blinding of outcome assessors not declared. Subjective and objective outcome measures; Invalid AOFAS score Lack of statistical analysis
López-Oliva et al (45)	Subtalar arthrodesis with VIRA system with or without a corrective osteotomy AOFAS	Whereas 18 patients had arthrodesis, 5 had arthrodesis as well as corrective osteotomy. At a mean follow-up of 1.5 years, the AOFAS score increased from 42.1 to 71.6. However, clinical outcomes were significantly better ($p < .001$) in cases of arthrodesis alone, although patients who had both procedures improved considerably compared with preoperative status. Of the 11 cases without major incapacitation preoperatively, 8 were able to return to their previous occupation. Mean preoperative Bohler's angle for cases of in situ fusion was 11.29°, whereas those who had osteotomy as well was -4.7°. Although, patients who had arthrodesis and osteotomies had worse preoperative figures, both groups achieved the same mean postoperative values of 9.3°, which was maintained throughout the follow-up period. All 5 osteotomies showed consolidation with satisfactory correction in 4 cases. The union rate in all patients was 91%.	Subjective and objective outcome measures. Radiologic evaluation included a computed tomographic scan as well as radiographs. Invalid AOFAS score Blinding of outcome assessor not declared increasing the potential for detection bias. High risk of company interest. Long-term follow-up required for this technique to gain acceptability in the medical community.
Radnay et al (38)	Subtalar distraction arthrodesis AOFAS, MFS	There was a 92% initial union rate in both surgical and conservatively treated arms. The nonunion rate was slightly lower in the conservative arm of this study. No significant differences in functional outcome scores within different malunion types were found, perhaps due owing numbers of subjects within the types of CM.	Power calculation to determine sample size. Description of study could aid reproducibility. Standard protocol performed by 1 surgeon, which decreases the potential for performance bias. Subjective and objective outcome measures (radiographs and computed tomographic scans). There was an invalid AOFAS score. Blinding of the research nurse during the outcome retrieval process decreases the potential for detection bias. No drop out of subjects from the study occurred, eliminating the potential for attrition bias. No conflicts of interest.
Fan et al (46)	Subtalar distraction osteogenesis and arthrodesis AOFAS	At a mean follow-up of 1.2 years, the mean AOFAS score increased considerably from a mean of 25.3 preoperatively to 76.3 postoperatively. The mean time for bony fusion was 4.9 months. The mean calcaneal height increase was 12.5 mm. The calcaneal width decreased from 44.2 to 34.5 mm, which enhances cosmesis and ability to wear shoes. Of the 8 feet, 6 recorded no pain postoperatively and 2 had slight pain.	Description of study aids reproducibility. No conflicts of interest. The small sample size limits generalization to the population. Blinding of outcome assessor was not declared, which increases the potential for detection bias. Subjective and objective outcome measures. There was an invalid AOFAS score . Long-term follow-up is required for this technique to gain acceptability in the medical community.
Yavuz et al (47)	Isolated subtalar fusion with or without bone graft AOFAS	At a mean follow-up of 3.6 years, the mean AOFAS score significantly increased from 61.7 preoperatively to 84.2 postoperatively ($p = .001$). However, differences in preoperative and postoperative radiologic measurements were not significant. Complete union was achieved in 95% of patients. However, no significant difference in rate of union whether patients had bone grafting or not. The mean duration of radiologic union was 15.1 ± 5.24 weeks.	Subjective and objective outcome measures; there was an invalid AOFAS score. Competing interests were not declared. Blinding of the outcome assessor not declared, which increases the potential for detection bias. No drop out recorded.

Abbreviations: AOFAS, American Orthopaedic Foot and Ankle Society; CM, calcaneal malunion; MFS, Maryland Foot Score.

Table 5
Detailed results of group B studies

Study	ProceduresOutcome Measures	Results	Strengths & Limitations
Aly (11)	Corrective osteotomy (lateral opening wedge) AOFAS	At a mean follow-up of 4.7 years, the lateral talocalcaneal angle increased from a mean of 23° preoperatively to 34.4° postoperatively. The calcaneal height increased from of 44 to 49 mm. All differences in measurements were significant ($p < .05$), except for the lateral talocalcaneal angle. The valgus deformity was corrected in all patients. Of 34 feet, 91% had satisfactory outcomes with marked improvement in pain relief, gait abnormalities and walking distances. The mean AOFAS increased from 57 to 90.	Description of study could aid reproducibility. Subjective and objective outcome measures; there was an invalid AOFAS score. Objective outcome assessment done with digital radiographs by the surgeon and a radiologist. There was no drop out of subjects from the study eliminating the potential for attrition bias. There was a lack of blinding. Competing interests were not declared.
Rammelt et al (47)	Joint-preserving osteotomy AOFAS	At a mean follow-up of 2.6 years, all patients were satisfied with their results. The mean AOFAS score increased significantly ($p < .001$) from 16.25 to 79.25. The mean Bohler's angle increased from 15.5° to 28°. The mean talocalcaneal height increased from 67 to 77 mm.	Subjective and objective outcome measures were used; there was an invalid AOFAS score. The small sample was size. Blinding of outcome assessors was not stated. Competing interests were not declared.
Yu et al (48)	Joint-preserving osteotomy AOFAS	Outcomes were generally better at 2 years compared with the 1-year results. At the 2-year follow-up, 85% of patients had a stable, painless hind foot subjectively and clinically. They were satisfied and returned to preinjury work and activities. However, 1 patient required subtalar arthrodesis for subtalar arthritis at the 2-year follow-up. The mean AOFAS preoperative score significantly increased from 28.9 to 82.2 at 1 year and 85.9 at 2 years ($p < .05$). Postoperative differences in Bohler's angle, Gissane's angle, talus declination angle, talocalcaneal height, and calcaneal width were significant ($p < .05$).	The selection criteria were well defined. Description of the study aids reproducibility. Subjective and objective outcome measures were used. Radiologic evaluation included computed tomographic scans as well as radiographs; there were an invalid AOFAS score. This is the only study that gave postoperative details at 1 and 2 years of follow-up. There were no conflicts of interest. The sample size was small. Blinding of outcome assessors was not stated.

Abbreviation: AOFAS, American Orthopaedic Foot and Ankle Society.

the deformity in the transverse and sagittal planes, was shown to be effective with significant increases in calcaneal length and height (58). However, calcaneal osteotomies tend to yield poor outcomes in patients with existing subtalar arthritis, which might be responsible for the poor outcomes in 3 of 34 patients in this study (58). Hence, in the event of subtalar arthritis with hind foot malalignment, subtalar arthrodesis as well as a calcaneal osteotomy is required. In contrast, the Dwyer closing wedge osteotomy used by Radnay et al (38) and Clare et al (37) to correct varus malalignment in their studies shortened the lateral calcaneal column relative to the medial (58). The aim in both osteotomies was to realign the calcaneus in neutral to 5° to 7° of valgus (59).

Rammelt et al (22) and Yu et al (6) registered considerable success with joint-preserving osteotomy and subtalar joint salvage in Stephens type I or Rammelt type 0 CM (10,57), with recorded improved results with time. For instance, at the 1-year follow-up, 8 of 24 patients had mild pain occasionally and 6 had decreased range of motion of the subtalar joint, whereas at the 2-year follow-up, 6 patients had mild pain occasionally and 3 had decreased range of motion of the subtalar joint. All patients were satisfied and did not have any difficulties with activities of daily living.

In the study by Yu et al (6), 85% of patients returned to their preinjury activities at final follow-up and 10% changed their occupation. Only 1 patient did not go back to work and 1 patient had persistent pain for which he underwent subtalar arthrodesis after the 2-year follow-up. There were also corresponding and significant increases in the AOFAS score, Bohler's angle, Gissane's angle, and the talocalcaneal height talar declination angle, and a decrease in the calcaneal width, which all enabled the patient to wear normal shoes eventually.

Rammelt et al (22) recorded similar success in their study with no record of patients requiring subtalar arthrodesis at mean follow-up of 2.6 years. However, sample sizes limit the external validity of the 2 previous studies. Additionally, both studies require long-term follow-up for further evaluation of this technique. Nonetheless, this technique may be suitable for patients who are less than 12 months after their initial injury with minimal arthritic changes.

Group C

Clare et al (37) successfully achieved plantigrade feet in physiologic alignment in 93% of patients with types I, II, and III malunions. Although this was the only study that used the valid albeit nonspecific SF-36 outcome measure, there was no significant difference among the types of CM in all 3 outcome measures used. This finding is perhaps due to the small sample sizes within each type of CM. There was a significant difference in talocalcaneal height in type III CM relative to the other types, which might be attributed to the severity of type III malunions. A significant flaw in the study was the lack of preoperative data.

Al-Ashhab (49) achieved a 100% union rate at an average of 12.2 weeks in patients with type II CM. There was also considerable increase in the AOFAS scores and talocalcaneal height. Both studies in group C substantiate the usefulness of the Stephens and Sanders classification and treatment protocol in the surgical management of CM.

Table 6
Detailed results of group C studies

Study	ProceduresOutcome Measures	Results	Strengths and Limitations
Clare et al (37)	Combined procedures based on the Stephen and Sanders CM classification AOFAS, MFS, SF-36.	At a minimum follow-up evaluation of 2 years, 93% of patients who had arthrodesis achieved union. Ninety-three percent of all cases achieved plantigrade feet in physiologic neutral or slight valgus alignment. Postoperative talocalcaneal height was significantly greater for type III CM relative to other groups ($p = 0.021$). However, there was no statistically significant differences among the types of CM in terms of outcome scoring systems.	Description of study aids reproducibility. Standard treatment protocol used by 1 surgeon reduced the potential for performance bias. There were no conflicts of interest. The subjective and objective outcome measures were valid. Radiologic evaluation included computed tomographic scans as well as radiographs; the AOFAS score was invalid. Preoperative data were not provided. Blinding was not declared.
Al-Ashhab (49)	Combined procedures based on Stephen and Sanders CM classification AOFAS	All patients managed had type II CM. At a mean follow-up of 1.1 years, the mean AOFAS score increased from 33 to 69 based on a maximum achievable score of 94. There was a 100% union rate, and the mean time to union was 12.2 weeks. Mean talocalcaneal height increased from 68.4 to 74.3 mm at immediately postoperative to 73.3 mm at the final follow-up. The mean calcaneal width decreased from 5.0 to 2.8 mm.	Description of study aids reproducibility. Ther were no conflicts of interest. Subjective and objective outcome measures were used; the AOFAS score was invalid. There was a lack of statistical analysis. Designation and blinding of outcome assessor were not declared, increasing the potential for detection bias. There is a lack of long-term follow-up.

Abbreviations: AOFAS, American Orthopaedic Foot and Ankle Society; CM, calcaneal malunion; SF-36, Short Form-36.

Quality Assessment of Included Studies

The Cochrane Risk of Bias in Non-randomized Studies of Interventions assessment tool Version 7, which was published in March 2016, has been applied to all studies in this review. The following domains were considered to look for any potential biases: confounding factors, selection, classification of interventions, deviations from intended intervention, missing data, measurement of outcomes, and selection of reported result. The risk of bias in each of these domains was appraised low, moderate, high, or no information to come to a conclusion (Table 3). A study is deemed high risk of bias when there is a high risk of bias (HRB) in at least 1 of the 7 domains evaluated. The overall risk of bias was considered moderate in 7 studies and 3 were considered HRB.

Group A

Two of the 5 studies in group A were considered HRB. Radnay et al (38) was considered HRB owing to the lack of preoperative AOFAS score for the conservatively treated arm, which made it difficult to assess the full impact of surgical management in this group of patients. Second, radiologic measurements were not declared in this study. This lack might be attributed to the initial hypothesis of the authors to prove that initial surgical management yielded better functional outcomes than conservatively treated patients. López-Oliva et al (45) was regarded HRB owing to the conflict of interest involving one of the authors. Postoperative physiotherapy and compliance, which can be regarded as confounding factors, were not discussed in any of the studies. Another source of confounding across the studies in group A was the lack of specific time points for postoperative follow-up, which means that follow-up of the patients could have occurred at different times within the period of postoperative follow-up.

Group B

All 3 studies in group B were considered moderate risk of bias. There was a lack of information on the designation and blinding of outcome assessors as well as postoperative physiotherapy regimen, which could increase the potential for detection and intervention bias, respectively. Unfortunately, the studies' authors did not respond to emails sent by the authors of this review asking for further clarification about these different domains.

Group C

One study was regarded HRB and the other was considered moderate risk of bias. Clare et al (37) was considered HRB owing to the lack of baseline figures of subjects, which decreased the study's validity and reliability. Additionally, details of physical therapy regimen and compliance, which could constitute a source of confounding, were not discussed by the authors.

Rehabilitation in Included Studies

Periods of postoperative non-weightbearing ranged from 6 to 12 weeks and was progressed based on radiographic evidence of union, as declared by some of the included studies. Rehabilitation of patients, which is an integral part of the comprehensive orthopedic and trauma care, was not discussed adequately across the included studies. Various options of physical therapy modalities have been found to make remarkable difference in the outcome of orthopedic patients (60). Hence, the role of physiotherapy in the included studies cannot be determined properly.

Complications in Included Studies

Group A

López-Oliva et al (45) and Fan et al (46) reported persistent pain postoperatively. The heel pain in the former study may be attributed to the VIRA implant, whereas the pain experienced by 1 patient in the latter study may be as a result of injury to the surrounding tissues while the ankle joint was distracted. These issues were resolved at the end of the follow-up period. However, no details of intervention, if any, to alleviate the pain were documented. Cases of superficial infection were reported by Radnay et al (38) and El-Soufy (44); there was as a case of a deep infection reported by Radnay et al (38). Radnay et al (38) and Yavuz et al (47) recorded 3 cases and 1 case of nonunion, respectively. This complication may be ascribed to the fact that about 60% of patients in the Radnay et al (38) study were smokers, which predisposes to

delayed wound healing and nonunion (59,61). For this reason, some authors in the literature suggest bone grafting at the initial operation to avoid nonunion particularly in smokers (27,59). Finally, Yavuz et al (47) reported 2 cases of asymptomatic mid-tarsal arthritis, and El-Soufy (44) reported 3 cases of sural neuralgia.

Group B

Yu et al (6) reported 6 patients with wound edge necrosis; 2 patients had a superficial infection. Yu et al (6) also had to arthrodese 1 subtalar joint 2 years postoperatively on account of subtalar arthritis. This finding indicates that the attempt of joint-preserving osteotomy in this patient proved unfruitful, perhaps owing to an unrecognized preexisting subtalar arthritis preoperatively. For this reason, calcaneal osteotomies are not recommended in individuals who have preexisting subtalar arthritis (58). Rammelt et al (22) registered no minor or major postoperative complications. Although 2 patients underwent implant removal and subtalar arthrolysis on account of unrelenting stiffness of the subtalar joint at 1 year after the surgery, no patient required subtalar arthrodesis in the Rammelt study.

Group C

Delayed wound healing was also a hurdle in 24% of cases in the study by Clare et al (37), as well as 3 cases of nonunion. Al-Ashhab (49) reported the only study that recorded complex regional pain syndrome as a complication, with 27% of patients affected. Superficial wound infection also occurred in 18% of patients, who were all smokers. Detailed results of groups A, B, and C are compiled in Tables 4, 5, and 6, respectively.

Limitations of This Review

Clinical and methodologic heterogeneity of included studies did not permit quantitative synthesis of data into a meta-analysis, but led to a broad-based narrative review. In addition, the inclusion criteria for this review considered only studies published in English; more comprehensive reviews may include studies published in other languages.

Implications for Future Research

Future observational studies with long-term outcomes assessment should ensure the use of adequate sample sizes by performing power calculations to enable the accurate detection of statistical significance, because only 1 study in this review has used a power calculation. Second, the development of a valid, reliable, and user-friendly outcome measure for foot and ankle conditions will decrease the potential for detection bias, thereby increasing the internal validity of future studies. Finally, health care professionals, particularly researchers, should be familiar with the Cochrane Risk of Bias In Non-randomized Studies of Interventions assessment tool version 7, because this instrument will aid with the design and implementation of more methodologically sound research, resulting in more valid and reliable evidence to inform clinical practice.

In conclusion, despite the limitations observed in the evidence gathered from the included observational studies, there seems to be largely favorable outcomes after the surgical management of CM in patients who underwent initial conservative treatment of calcaneal fractures. There is clear evidence in the current literature that appropriately indicated procedures are effective in terms of pain alleviation, correction of deformity, and improved function. Long-term outcomes, however, may encourage the acceptability to joint-preserving osteotomies, subtalar arthrodesis with the VIRA implant, and subtalar distraction osteogenesis. The role of physiotherapy in achieving the favorable outcomes of surgery has not been clearly elucidated in the included studies, which might have hindered a more comprehensive assessment of the surgical interventions investigated in this review.

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