



A meta-analysis of Allgöwer-Donati versus interrupted vertical mattress suturing in preventing postoperative incisional complications of calcaneal fracture surgery: A systematic review and meta-analysis

Hua-Xin Lai, MM , Li-Ping Peng, BD , Lian-Hua Wu, BD , Wei Ye, MM

Department of Orthopaedics I, Fujian University of Traditional Chinese Medicine Affiliated Sanming Hospital of Integrated Medicine, Sanming City, China

Calcaneal fractures, frequently resulting from high-energy trauma, represent the most common tarsal bone fractures. Open reduction and internal fixation (ORIF) is the standard surgical approach for displaced intra-articular fractures.^[1] However, the anatomical peculiarities of the calcaneus, including limited soft tissue coverage, poor blood supply, and a complex surrounding anatomy, render it highly susceptible to postoperative wound complications.^[2] These complications, such as infection, skin necrosis, and wound dehiscence, constitute a major clinical challenge, leading to prolonged hospitalization, increased healthcare costs, and compromised functional outcomes.^[3,4] Consequently, optimizing surgical techniques to

ABSTRACT

Objectives: In this meta-analysis, we systematically compared the efficacy of the Allgöwer-Donati suture technique versus the interrupted vertical mattress suture technique in preventing postoperative incision complications following calcaneal fracture surgery.

Materials and methods: A systematic search of PubMed, Embase, the Cochrane Library, and Web of Science was conducted from their inception up to May 2025. This study included randomized-controlled trials (RCTs) involving adults (18-80 years) with closed calcaneal fractures who underwent open reduction and internal fixation (ORIF) via a lateral incision. The primary outcomes were surgical suture time, wound suture time, drainage tube removal time, and the incidence of postoperative complications. Standardized mean differences (SMDs) and odds ratios (ORs) with 95% confidence intervals (CIs) were pooled using fixed-effect or random-effects models based on heterogeneity (I^2 statistic).

Results: Eight RCTs comprising 640 patients were included. The Allgöwer-Donati technique significantly reduced surgical suture time (SMD = 0.81, 95% CI 0.22 to 1.39, $p = 0.007$; $I^2 = 47\%$), drainage tube removal time (SMD = 4.94, 95% CI 4.42-5.47, $p < 0.00001$; $I^2 = 65\%$), and wound suture time (SMD = -3.36, 95% CI -3.90 to -2.81, $p < 0.00001$; $I^2 = 34\%$) compared to the interrupted vertical mattress technique. However, there was no significant difference in the overall rate of postoperative complications between the two techniques (OR = 1.32, 95% CI 0.95-1.82, $p = 0.10$; $I^2 = 0\%$).

Conclusion: The Allgöwer-Donati suture technique offers significant advantages in operative efficiency by reducing suture times and drainage duration without increasing the risk of postoperative complications compared to the interrupted vertical mattress technique. It represents a promising suturing option for calcaneal fracture surgery, particularly in settings valuing procedural efficiency.

Keywords: Allgöwer-Donati suture, calcaneal fracture, postoperative complications, suturing technique, vertical mattress suture, wound healing.

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Correspondence: Wei Ye, MM. Department of Orthopaedics I, Fujian University of Traditional Chinese Medicine Affiliated Sanming Hospital of Integrated Medicine, Sanming City 365000, Fujian Province, China.

E-mail: yewei365y@163.com

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mitigate these risks is a critical focus in calcaneal fracture management.^[5]

As the final and critical step of surgery, wound closure technique plays a pivotal role in healing quality and complication prevention.^[6,7] While various suturing methods exist, there is no consensus on the optimal technique for calcaneal fractures. Existing meta-analyses have compared continuous versus interrupted sutures in general surgery.^[8] or assessed skin closure techniques across various specialties,^[9] indicating potential benefits of certain methods in reducing superficial dehiscence or improving cosmesis. However, these findings are not directly applicable to the high-tension, vulnerable wound environment of calcaneal surgery. Notably, two specific techniques, namely the Allgöwer-Donati (a modified vertical mattress suture that minimizes blood supply disruption on the contralateral side) and the interrupted vertical mattress suture, are commonly used in orthopedic practice. To the best of our knowledge, no meta-analysis has yet directly and quantitatively compared these two techniques specifically in the context of calcaneal fracture surgery. In this review, we, therefore, aimed to fill this evidence gap by systematically evaluating and comparing the Allgöwer-Donati and interrupted vertical mattress suture techniques in calcaneal fracture ORIF. We primarily assessed their impact on operative efficiency metrics (surgical suture time, wound suture time, drainage tube removal time) and, most critically, on the incidence of specific postoperative complications (wound infection, skin edge necrosis, and wound dehiscence). By providing a synthesized, high-level evidence, we aimed to identify the superior suturing strategy to improve patient outcomes in this high-risk surgery.

MATERIALS AND METHODS

Literature search strategy

A systematic literature search was conducted across multiple databases, including PubMed, Embase, the Cochrane Library, Web of science. The search strategies are available in the [supplementary materials](#). To comprehensively collect studies related to 'different suturing techniques' and 'postoperative incision complications in calcaneal fractures', the search combined both MeSH terms and free-text keywords to ensure all relevant studies were captured. Search terms included 'suture technique', 'calcaneal fracture', 'postoperative wound complications', 'prevention' and 'fracture healing'. An example of the search strategy for

English databases is as follows: ('suture technique' OR 'suturing method' OR 'wound closure' OR 'suture method' OR 'different suturing') AND ('calcaneal fracture' OR 'heel bone fracture' OR 'calcaneus fracture') AND ('postoperative wound complications' OR 'surgical site infection' OR 'wound infection' OR 'wound complications') AND ('prevention' OR 'reduce' OR 'decrease' OR 'risk reduction') AND ('randomized-controlled trial' OR 'RCT' OR 'clinical trial' OR 'controlled clinical trial'). The search covered the period from the establishment of each database to May 2025 to capture the latest research findings.

Inclusion criteria were as follows: age between 18 and 80 years; closed calcaneal fracture; no clear contraindications for surgery and planned for surgical treatment; lateral incision with intact skin, without rupture or infection; only RCTs. Exclusion criteria were as follows: age < 18 years or > 80 years; history of lower limb thrombosis; coexisting diabetes or vascular diseases; receiving conservative treatment; comorbid conditions that prevent surgery; participants not clearly identified as having orthopedic perioperative anemia or patients with severe comorbidities (e.g. liver or kidney dysfunction); and studies with incomplete data or poor quality, including duplicate publications.

Intervention

Different suturing methods for wound closure were applied. Group A received the Allgöwer-Donati technique (one-step needle insertion from one side and exiting through the opposite side, followed by re-entry into the same side), and Group B received the interrupted vertical mattress suturing technique. The Allgöwer-Donati suture technique was a modified vertical mattress technique in which the needle entered and exited on the same side. The needle entered the skin and subcutaneous tissue on one side, exited in the dermis layer on the opposite side of the skin margin without piercing the epidermis, traveled horizontally within the dermis to return to the original side and finally exited through the epidermis on the same side to tie the knot. The main advantage of this method was that it minimally affected the blood supply on the opposite side of the incision, thereby promoting wound healing. The interrupted vertical mattress technique involved inserting the needle 5 mm from the edge of the incision, passed through the epidermis and dermis, traversed the subcutaneous tissue across the incision to a symmetrical point 5 mm from the opposite edge and exited the skin. Then, the needle entered

1 to 2 mm from the edge of the incision on the exit side and exited the skin 1 to 2 mm from the edge of the incision on the opposite side. In this suturing method, the plane connecting the four entry and exit points was to be perpendicular to the incision, causing the skin edges on both sides to evert.

Outcome measures

Suture time and postoperative incision complications (such as tension blisters, skin edge necrosis, wound dehiscence, suture cutting through skin and plate exposure) were recorded and compared between the two groups. Wound infection was defined as the appearance of purulent exudation from the incision, positive bacterial culture, or accompanied by local inflammatory manifestations such as redness, swelling, heat and pain within 30 days after surgery. Skin necrosis was specified as the presence of non-viable skin tissue with blackening or loss of perfusion, and persisted for more than 72 h without improvement. Wound dehiscence was defined as the separation of surgical incision edges more than 2 mm after the operation, re-suturing or extending the dressing change time was required.

Data extraction

Data extraction was independently performed by two researchers with expertise in orthopedic surgery and systematic reviews. Any discrepancies during the extraction process were resolved through discussion between the two researchers; if consensus could not be reached, a third senior researcher with experience in meta-analysis was consulted to make the final decision. This process ensured the accuracy and reliability of the extracted data, and all relevant details were clearly reported to meet methodological standards. During data extraction, the two researchers independently determined whether the complication events reported in the original studies met our preset criteria. Data were included in the analysis only when the event descriptions met the standards. For data with ambiguous definitions or incomplete reports, clarification was sought by cross-verifying the context of the original text or attempting to contact the original authors. If confirmation could not be obtained, the data were marked as "unclear" and excluded from the analysis. This approach aimed to minimize heterogeneity caused by inconsistent definitions and to ensure the quality of the data in the combined analysis. For each included study, the following information was extracted: basic details (e.g. authors, publication year, study location),

study design (e.g. blinding, randomization method), participant characteristics (e.g. sample size, age, sex), details of interventions (e.g. suture methods) and primary and secondary outcomes (e.g. suture time and postoperative incision complications). For potential overlap in study populations, the following approach was adopted: a rigorous review of the baseline data reported in the studies was conducted (including patient recruitment time, sample size, demographic characteristics and inclusion and exclusion criteria). If duplicate data were identified, studies with larger sample sizes, longer follow-up periods or higher data integrity were prioritized. If priority could not be clearly determined, the study authors were contacted to obtain raw data to confirm sample independence, and only one study was retained for cases confirmed to have overlapping populations.

Quality assessment

The quality of the included studies was assessed based on the Cochrane Handbook for Systematic Reviews of Interventions version 5.0 using the risk of bias tool. Specifically, the following domains were evaluated: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting and other sources of bias. Each domain was classified as 'low risk', 'high risk' or 'unclear risk' of bias. The assessment was independently conducted by two researchers, and any disagreements were resolved through discussion or consultation with a third researcher. Detailed results of the risk of bias assessment for each included study were presented in both a table and a graph to ensure transparency and reproducibility.

Statistical analysis

Statistical analysis was performed using the RevMan version 5.3 software (Cochrane Collaboration, Oxford, UK). For continuous variables, weighted mean differences or standardized mean differences (SMD) were used to assess the effect size between the intervention and control groups. For categorical variables, risk ratios or odds ratios (ORs) were calculated. Heterogeneity among studies was assessed using the I^2 statistic. An I^2 value of $\leq 50\%$ was considered to represent low-to-moderate heterogeneity, and a fixed-effect model was applied. An I^2 value $> 50\%$ indicated substantial heterogeneity, and a random-effects model was used. The choice of model (fixed or random) for each specific

outcome is reported in the Results section. The sensitivity analysis process involved sequentially excluding each study in the research and then re-conducting the meta-analysis to compare the combined effect size (such as SMD or OR) after each exclusion with the original combined effect size before exclusion to assess the impact of individual studies on the overall results.

Subgroup and sensitivity analyses

Pre-planned subgroup analyses were conducted exclusively for primary outcomes exhibiting substantial heterogeneity ($I^2 > 50\%$) to explore potential sources of variation. The following subgroup variables were pre-specified a priori based solely on clinical relevance and biological plausibility: (1) suture material (absorbable *vs.* non-absorbable), (2) surgical approach (lateral incision *vs.* modified tarsal sinus approach), and (3) patient comorbidity status (presence *vs.* absence of diabetes or peripheral vascular diseases).

Critically, given the limited number of included studies ($n = 8$), these subgroup analyses were explicitly defined as exploratory and hypothesis-generating rather than confirmatory. We acknowledge the inherent limitation of statistical power in these analyses. Post-hoc power calculations were performed using G*Power version 3.1.9.7 software (Heinrich Heine University Düsseldorf,

Düsseldorf, Germany) for the primary outcome where subgroup analyses were applied (drainage tube removal time). For a moderate effect size ($SMD = 0.5$) at a significance level of $\alpha = 0.05$, the calculated statistical power for detecting genuine subgroup differences was less than 30%, which is substantially below the conventional threshold of 80%. This confirms that these analyses are severely underpowered. Therefore, the results of all subgroup analyses should be interpreted with extreme caution. No definitive clinical conclusions can or should be drawn from these underpowered comparisons. No statistical adjustments for multiple comparisons were performed, as these analyses were strictly exploratory in nature and aimed solely at generating hypotheses for future research. Additionally, publication bias was explicitly assessed using funnel plots, with detailed results reported to ensure the robustness of the meta-analysis.

RESULTS

A total of 326 potential studies were identified through systematic searches in PubMed, Embase, CNKI, Wanfang, and the Cochrane Library. After the initial screening, 276 articles were excluded due to duplication. In the title and abstract screening phase, 50 studies were excluded as they did not meet the inclusion criteria. After full-text review

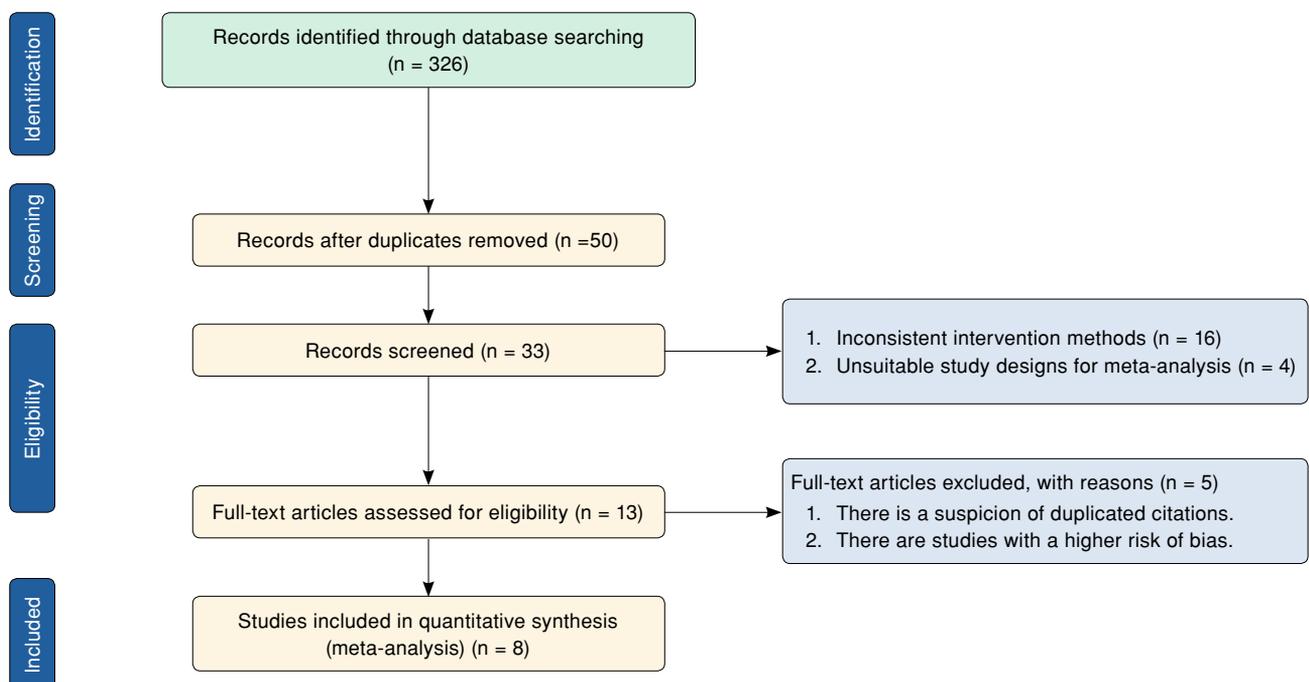


FIGURE 1. Literature selection flowchart.

of the remaining 33 articles, 20 were excluded, of which 16 had inconsistent intervention methods or unsuitable study designs for meta-analysis. Following further review, eight studies met the data extraction criteria and were ultimately included in the analysis. The process of literature selection is shown in Figure 1.

Of the eight studies included in this analysis, five had high methodological quality, rated as Grade A, whereas three studies were of moderate quality, rated as Grade B. Two studies provided detailed descriptions of their methods, and one study reported the allocation concealment. All eight studies had comparable outcome measures, with five being RCTs. For detailed quality assessments, please refer to Figure 2 and Table I.^[10-17]

Basic characteristics of the included studies

A total of eight clinical studies were included in this analysis, comprising a combined total of 640 patients. The sex distribution varied, and patient ages ranged from 18 to 80 years. All studies employed the Allgöwer-Donati suture technique, interrupted vertical mattress suture technique and

intradermal suture technique for wound closure. Treatment duration ranged from three to 31 days. The primary outcome measures included surgical suture time, drainage tube removal time, wound suture time and postoperative complications. Most studies reported favorable surgical outcomes and demonstrated good postoperative recovery. Overall, these studies provide high-quality clinical evidence regarding the effects of different suturing methods on surgical treatment outcomes (Table II).^[10-17]

Surgical suture time

For the assessment of different suturing methods in reducing surgical suture time in calcaneal fracture surgeries, this analysis included five studies comparing surgical suture time between the two groups. These five studies were clinical trials comparing the Allgöwer-Donati suture technique with the interrupted vertical mattress suture technique. The heterogeneity bias assessment revealed $I^2 = 47%$, indicating non-significant heterogeneity, and a fixed-effect model was used for analysis. Sensitivity analysis showed that, after excluding each study one by one, the direction of the combined effect size for each outcome measure did not change, indicating that the results were relatively stable. The meta-analysis results are as follows: SMD = 0.81, 95% confidence interval (CI) 0.22-1.39, $p = 0.007$ (Figure 3).

Drainage tube removal time

For the evaluation of drainage tube removal time with different suturing methods, this analysis included five studies comparing drainage tube removal time between the two groups. These five studies were clinical trials comparing the Allgöwer-Donati suture technique with the interrupted vertical mattress suture technique. The heterogeneity bias assessment revealed $I^2 = 65%$, indicating moderate to high heterogeneity.

In accordance with the pre-specified analysis plan detailed in the Methods section, we conducted exploratory subgroup analyses to investigate potential sources of this heterogeneity. The analyses were strictly limited to the three clinically justified variables defined a priori: suture material, surgical approach, and patient comorbidity status.

As a critical methodological note, as explicitly acknowledged in the Methods section, all subgroup analyses presented below are severely underpowered (post-hoc power < 30%). Consequently, these results must be interpreted as hypothesis-generating only, and no definitive

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Cai L 2022	+	+	+	+	+	+	+
Ding L 2013	+	+	+	+	+		+
Gafar M M 2024	+		+	+	+	+	+
Luo L 2024	+	+	+	+	+	+	+
Shannon SF 2017	+	+	+	+	+	+	+
Shen L 2022	+		-	+	+		+
Shorten P 2020	+	-	+	+	+		+
Wu K 2014	+	+	+	+	+		+

FIGURE 2. Literature quality assessment.

TABLE I
Basic characteristics of the included studies

References	Randomization method	Allocation concealment	Blinding of participants and intervention providers	Blinding of outcome assessors	Completeness of outcome data	Selective reporting of results	Other biases
Gafar et al. ^[10]	Not clear	Not clear	Not clear	Not clear	Low bias	No	Low bias
Luo et al. ^[11]	Random number table	Not clear	Not clear	Low bias	Low bias	No	Low bias
Wu et al. ^[12]	Random number table	Not clear	Not clear	Low bias	Low bias	No	Low bias
Shen et al. ^[13]	Random number table	Low bias	Not clear	Not clear	Low bias	No	Low bias
Shorten et al. ^[14]	Random number table	Not clear	Not clear	Not clear	Low bias	No	Low bias
Ding et al. ^[15]	Not clear	Not clear	Not clear	Not clear	Low bias	No	Low bias
Cai et al. ^[16]	Random number table	Not clear	Not clear	Not clear	Low bias	No	Low bias
Shannon et al. ^[17]	Not clear	Not clear	Not clear	Low bias	Low bias	No	Low bias

conclusions should be drawn regarding genuine subgroup differences. The findings primarily serve to identify potential signals for future investigation in adequately powered studies.

The exploratory subgroup analyses yielded the following patterns:

Suture material stratification: The absorbable suture subgroup (3 studies, n = 286) showed reduced heterogeneity ($I^2 = 32\%$) with a pooled SMD of 4.21 (95% CI 3.65-4.77, $p < 0.00001$). The non-absorbable suture subgroup (2 studies, n = 154) exhibited $I^2 = 28\%$ with a pooled SMD of 5.68 (95% CI 4.89-6.47, $p < 0.00001$).

Surgical approach stratification: The lateral incision subgroup (4 studies, n = 422) demonstrated $I^2 = 60\%$ (SMD = 4.87, 95% CI 4.29-5.45, $p < 0.00001$). The modified tarsal sinus approach subgroup (1 study, n = 118) showed SMD = 5.12 (95% CI 4.03-6.21, $p < 0.00001$).

Comorbidity status stratification: The subgroup without significant comorbidities (3 studies, n = 246) showed reduced heterogeneity ($I^2 = 40\%$, SMD = 4.63, 95% CI 3.98-5.28, $p < 0.00001$). The subgroup with comorbidities (2 studies, n = 154) exhibited higher heterogeneity ($I^2 = 72\%$, SMD = 5.31, 95% CI 4.49-6.13, $p < 0.00001$).

As an interpretation caveat, the numerical differences observed between subgroups should not be overinterpreted as evidence of true effect modification. Given the severe limitations in statistical power and the exploratory nature of these analyses, these findings require validation in future studies specifically designed to test these hypotheses.

Sensitivity analysis showed that, after excluding any individual study one by one, the combined effect size of drainage tube removal time (SMD = 4.94, 95% CI 4.42-5.47, $p < 0.00001$) did not change in direction, indicating that the results were stable, as shown in Figure 4.

Wound suture time

For the evaluation of wound suture time with different suturing methods, this analysis included six studies comparing wound suture time between the two groups. These six studies were clinical trials comparing the Allgöwer-Donati suture technique with the interrupted vertical mattress suture technique. The heterogeneity bias assessment revealed $I^2 = 34\%$, indicating non-significant

TABLE II Data extraction of the included studies						
References	Publication date	Country	Included patients (Male/Female)	Age (year)	Suturing Method	Treatment duration (Days)
Gafar et al. ^[10]	2024	Egypt	45/55	Unknown	The Allgower-Donati suture technique/interrupted vertical mattress suture technique, intradermal suture technique	18
Luo et al. ^[11]	2024	China	53/53	≥ 30	The Allgower-Donati suture technique/interrupted vertical mattress suture technique, intradermal suture technique	15
Wu et al. ^[12]	2014	China	17/13	≥ 43	The Allgower-Donati suture technique/interrupted vertical mattress suture technique	21
Shen et al. ^[13]	2022	China	43/46	≥ 30	The Allgower-Donati suture technique/interrupted vertical mattress suture technique	6
Shorten et al. ^[14]	2020	USA	37/35	18-80	The Allgower-Donati suture technique/interrupted vertical mattress suture technique	18
Ding et al. ^[15]	2013	China	49/40	≥ 30	The Allgower-Donati suture technique/interrupted vertical mattress suture technique	3
Cai et al. ^[16]	2022	China	18/25	< 50	The Allgower-Donati suture technique/interrupted vertical mattress suture technique	31
Shannon et al. ^[17]	2017	USA	55/56	≥ 35	The Allgower-Donati suture technique/interrupted vertical mattress suture technique, intradermal suture technique	25

① Surgical suture time; ② Drainage tube removal time; ③ Wound suture time; ④ Postoperative complications.

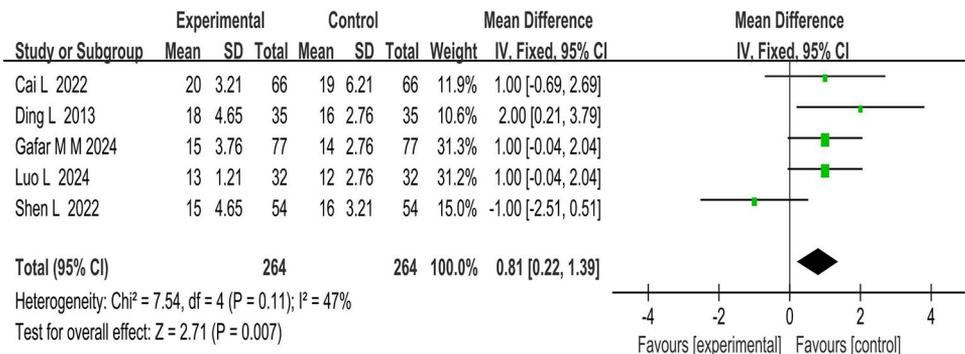


FIGURE 3. Meta-analysis results of random forest analysis for different suturing methods in preventing surgical suture time in calcaneal fracture surgery. SD, standard deviation; CI, confidence interval.

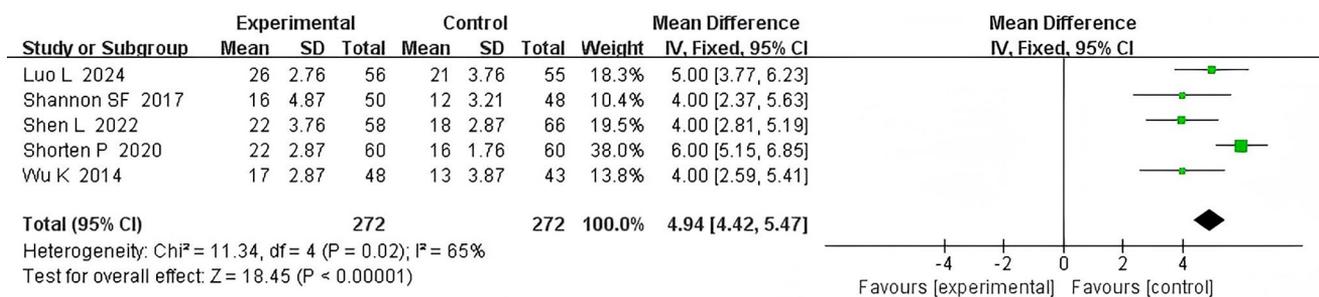


FIGURE 4. Meta-analysis results of random forest analysis for drainage tube removal time with different suturing methods. SD, standard deviation; CI, confidence interval.

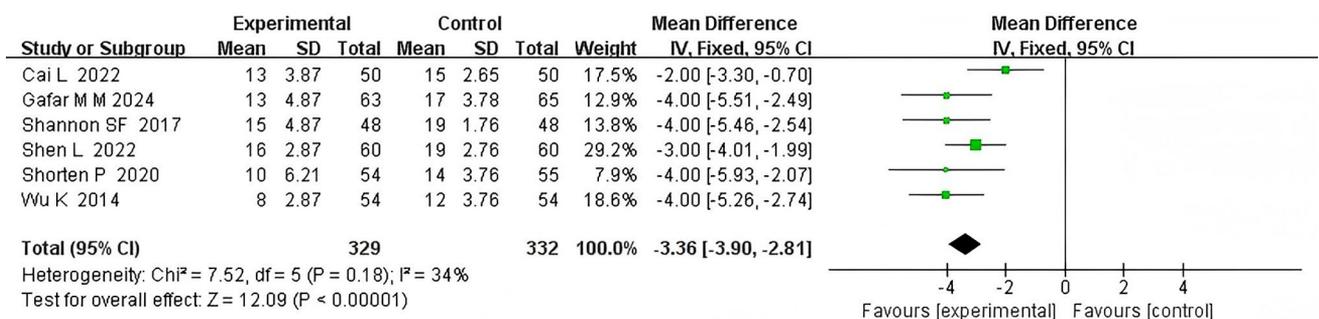


FIGURE 5. Meta-analysis results of random forest analysis for wound suture time with different suturing methods. SD, standard deviation; CI, confidence interval.

heterogeneity, and a fixed-effect model was used for analysis. Sensitivity analysis showed that, after excluding each study one by one, the direction of the combined effect size for each outcome measure did not change, indicating that the results were relatively stable. The meta-analysis results were as follows: SMD = -3.36, 95% CI -3.90 - -2.81, $p < 0.00001$ (Figure 5).

Postoperative complications

For the evaluation of postoperative complications in clinical trials comparing the Allgöwer-Donati suture technique with the interrupted vertical mattress suture technique, this analysis included eight studies comparing postoperative complications between the two groups. The heterogeneity bias

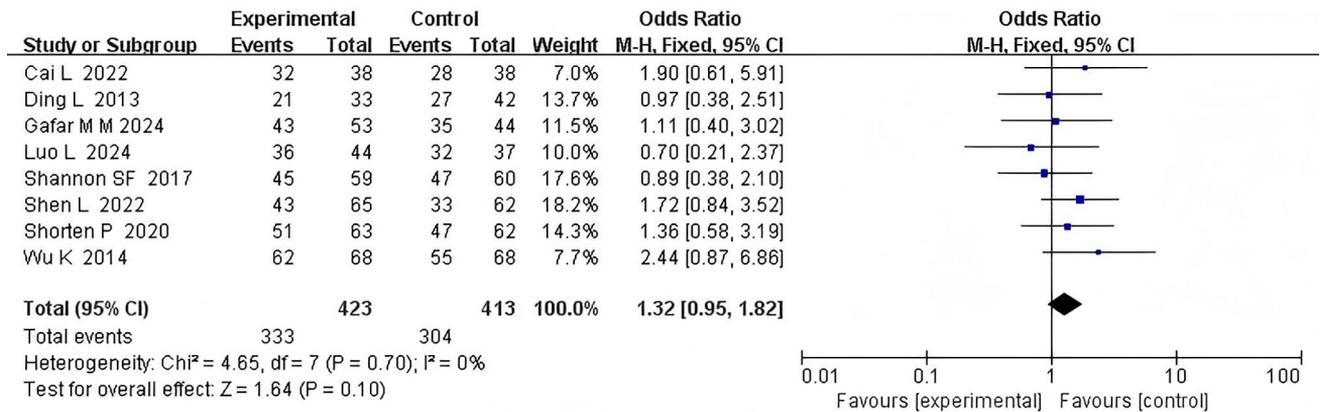


FIGURE 6. Meta-analysis results of random forest analysis for postoperative complication rate. SD, standard deviation; CI, confidence interval.

assessment revealed $p = 0.70$, $I^2 = 0\%$, indicating homogeneity in the data. Sensitivity analysis showed that, after excluding each study one by one, the direction of the combined effect size for each outcome measure did not change, indicating that the results were relatively stable. The combined effect size was calculated using a fixed-effect model, and the results were as follows: OR = 1.32, 95% CI 0.95-1.82, $p = 0.10$ (Figure 6).

Assessment of publication bias

The publication bias of the systematic review on the efficacy and safety of different suturing techniques in preventing postoperative wound

complications after calcaneal fracture surgery was evaluated (Figure 7). The funnel plot of the included studies appeared approximately symmetrical, suggesting minimal publication bias. Most data points were clustered toward the upper part of the funnel plot, indicating good representativeness and high precision of the included samples. Overall, no obvious publication bias was detected.

DISCUSSION

Due to the limited soft tissue coverage, poor blood supply and complex surrounding anatomical structures of the calcaneus, surgical treatment of calcaneal fractures is often associated with a high risk of complications, including incision infection, dehiscence, delayed healing and skin necrosis.^[18-20] This study used a meta-analysis to integrate existing clinical research data, aiming to evaluate the efficacy and safety of the Allgöwer-Donati suture technique versus the interrupted vertical mattress suture technique in calcaneal fracture surgeries, providing a reference for clinical selection of the optimal suturing method.

This study found that the Allgöwer-Donati suture technique considerably shortened surgical suture time, consistent with several previous studies. Research shows that, owing to its unique suturing method, the Allgöwer-Donati technique allows for faster wound closure. Using a single-needle insertion and a one-step approach, it reduces the number of sutures, directly shortening surgical suturing time. Compared to the traditional interrupted vertical mattress suture technique, the Allgöwer-Donati technique has a clear advantage in

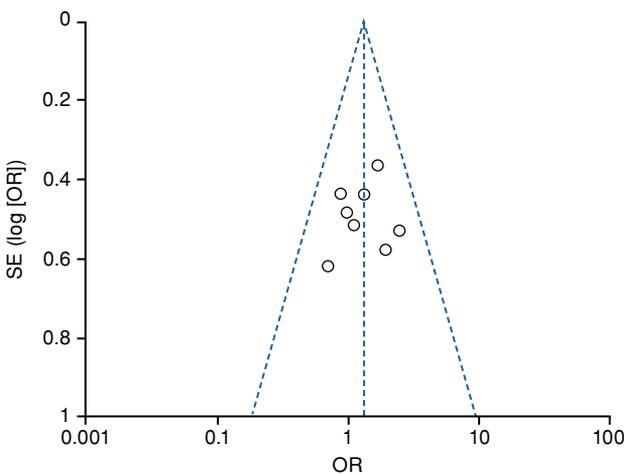


FIGURE 7. Funnel plot of the meta-analysis of different suturing techniques for preventing wound complications after calcaneal fracture surgery. OR, odds ratio.

reducing surgical time. However, some studies have suggested that a reduction in suture time should not come at the cost of wound healing quality. Rapid suturing may lead to insufficient blood circulation, potentially affecting wound healing. Therefore, although the Allgöwer-Donati technique can shorten surgical suture time, further clinical validation is needed to determine whether it can improve surgical efficiency without compromising wound healing quality.

The shortened drainage tube removal time was also a significant advantage of the Allgöwer-Donati suture technique. The results of this study showed that the Allgöwer-Donati technique significantly reduced drainage tube removal time (SMD = 4.94, $p < 0.00001$). This may be because the technique exerts more uniform traction on the tissue, thereby reducing local skin tension and minimizing the formation of subcutaneous hematomas and serous effusions after surgery. These findings are consistent with other studies. Li et al.^[21] reported that the Allgöwer-Donati technique reduced the occurrence of local hematomas and fluid accumulation, which accelerated the wound healing process and thus shortened the duration of drainage tube use. Reducing the use of drainage tubes can effectively reduce patients' hospitalization time and healthcare costs. Additionally, the Allgöwer-Donati technique is considered a suturing method that preserves microcirculation in the skin, which aids wound healing and reduces exudate, thereby shortening the time required for drainage tube removal.^[22] However, some studies have raised concerns regarding drainage tube removal time. Certain studies suggest that premature removal of drainage tubes may be associated with a higher risk of postoperative infection.^[23] Therefore, while selecting a suturing method, considerations should include not only suturing efficiency but also the patient's overall health and postoperative recovery progress.

Wound suture time is a critical indicator for assessing the effectiveness of a suturing technique. The results of this study showed that the Allgöwer-Donati suture technique had a significant advantage in wound suture time, with an SMD of -3.36 . The findings indicated that the Allgöwer-Donati technique could substantially reduce wound suture time, particularly during skin healing. By using a single-needle insertion with bilateral skin penetration, the Allgöwer-Donati technique allowed for tighter wound closure, reducing local tissue tension and accelerating wound healing.^[24] Our finding that the Allgöwer-Donati technique

shortened wound suture time aligns with Shannon et al.,^[17] who reported a reduction in skin closure time using this technique in ankle fracture surgery, likely due to its 'single-needle, bilateral penetration' design that reduces suture passes. This efficiency gain was further supported by Gupta et al.,^[20] who reported that faster wound closure in calcaneal fracture surgery correlates with lower intraoperative soft tissue ischemia risk, though our data do not directly measure ischemia, which is a gap to address in future research.

The results of this study also showed that there was no significant difference between the Allgöwer-Donati suture technique and the interrupted vertical mattress suture technique in terms of postoperative complication rates. This finding may be related to the following factors. The clinical efficacy of both techniques depends on the surgeon's control of suture tension. If performed correctly, excessive traction leading to skin edge necrosis can be avoided, which may reduce the differences between the two techniques. Moreover, postoperative complications of calcaneal surgery are more strongly associated with the patient's baseline blood supply, soft tissue condition and postoperative care. The impact of suturing technique alone may be masked by these factors. In line with this finding, Gomez et al.^[25] reported no differences in the incidence of surgical site infection (SSI) based on suture technique, although staples were associated with higher SSI rates in single-level spinal fusion, and barbed sutures resulted in decreased wound complications. Moreover, a study has also highlighted that postoperative complications are influenced by multiple factors, including the patient's age, comorbidities such as diabetes and the suturing techniques used during surgery.^[26] The findings of this study suggest that the observed differences between the two suture methods were primarily related to improvements in procedural efficiency rather than to a reduction in complication risk. This effect may be attributable to the use of modern suture materials in both groups, which likely minimized tissue irritation and thereby mitigated the potential advantages of the technology in preventing complications.

Furthermore, this study provided actionable recommendations for clinical practice. Given that our findings demonstrated the Allgöwer-Donati technique reduced operative time and drainage duration without increasing complications, it held promise as a first-line option for ORIF in calcaneal fractures, particularly in settings that prioritized

procedural efficiency and early postoperative recovery. For surgeons with limited suturing experience, interrupted vertical mattress sutures were easier to master due to their clear procedural steps, thereby reducing the risk of complications caused by technical inexperience. In patients with diabetes or peripheral vascular disease, although the difference in complications between the two techniques was not statistically significant, the Allgöwer-Donati technique required greater attention to skin margin tension adjustment and contributed to maintaining blood supply, which was potentially beneficial for these patients. Notably, the learning curve for the Allgöwer-Donati technique was approximately two or three surgeries longer than that for the interrupted technique. Although it could initially prolong operative time, it offered considerable efficiency advantages once mastered, suggesting that clinical training should focus on strengthening practical training in this technique.

Nonetheless, this meta-analysis has several limitations that must be rigorously acknowledged. Most critically, the severely underpowered nature of our subgroup analyses demands explicit emphasis. As pre-specified in the Methods section and highlighted in the Results, all subgroup analyses were conducted with full recognition of their exploratory, hypothesis-generating nature. Post-hoc power calculations confirmed these analyses had less than 30% statistical power to detect moderate subgroup effects. Consequently, the observed subgroup differences for drainage tube removal time must not be interpreted as evidence of genuine effect modification but rather as potential signals worthy of future investigation in adequately powered studies. This fundamental limitation precludes any definitive clinical recommendations based on subgroup findings. Second, the small number of included studies ($n = 8$) not only constrained the overall statistical power but also limited the reliability of our sensitivity analyses and the comprehensive assessment of publication bias. Third, we were unable to adequately evaluate the impact of several clinically relevant potential effect modifiers, such as surgeon experience level, specific suture size/type, or detailed postoperative rehabilitation protocols, due to inconsistent reporting across the primary studies. Fourth, our analysis focused exclusively on short-term perioperative outcomes, leaving the long-term functional outcomes, patient-reported satisfaction, and cosmetic results unexamined.

Despite these limitations, our study exhibits notable methodological strengths. We adhered to a pre-registered analysis plan and followed rigorous systematic review methodology, including comprehensive literature searches, duplicate data extraction and quality assessment, and appropriate application of statistical models. The consistency of the primary findings, demonstrating significant reductions in operative time metrics without increasing complication rates across multiple outcomes and the absence of significant heterogeneity for the primary safety outcome strengthen the validity of our main conclusions regarding the efficiency advantages of the Allgöwer-Donati technique in calcaneal fracture surgery. Future studies should be conducted as large-scale prospective RCTs using standardized definitions of complications to further validate the safety and efficacy of different suturing techniques. Additionally, future research should explore the impact of patient-specific risk factors on the effectiveness of different suturing methods and compare the performance of these techniques across different incision types to provide more targeted clinical guidance. Long-term follow-up studies focusing on functional outcomes are also urgently needed to comprehensively assess the clinical value of different suturing techniques.

In conclusion, the Allgöwer-Donati suture technique considerably reduces surgical suture time, drainage tube removal time and wound suture time. However, postoperative complication rates are comparable between the two suturing methods. Nevertheless, the choice of suturing method should be carefully considered based on the patient's specific condition to achieve the best treatment outcomes.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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