Research Article
E-ISSN : 3048-1368

Volume 06, Issue No. 03. 2024
P-ISSN : 3048-1376

The International Journal of Medical Science and Health Research

The Analysis Study of Characteristics and Effectiveness of Postoperative Rehabilitation Strategies in Ankle Fractures: A Comprehensive Systematic Review

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Article History :
Received date : 2024/08/12
Revised date : 2024/09/07
Accepted date : 2024/10/18
Published date : 2024/11/30

E-ISSN :
ISSN 3048-1368
9 773048 136000

P-ISSN :
ISSN 3048-1376
9 773048 137007

ABSTRACT

Background: Rehabilitation after ankle fracture surgery is critical for optimizing functional recovery. This systematic review explores various post-surgical rehabilitation strategies, including weight-bearing protocols, compression therapy, manual therapy, and active controlled motion, focusing on their efficacy in improving patient outcomes. **Methods**: A systematic review was conducted using seven randomized controlled trials and one retrospective analysis. Studies were assessed for interventions such as early versus delayed weight-bearing, compression stockings, manual therapy, active controlled motion, and ankle supports. Key outcomes included functional scores (OMAS, AOFAS), quality of life measures, range of motion, and return-to-activity timelines. **Results**: Early weight-bearing was associated with better functional recovery and earlier return to work, while active controlled motion improved range of motion and patient-reported outcomes. Compression therapy effectively reduced swelling and enhanced functional outcomes, but manual therapy showed limited benefits. Ankle supports, such as walker boots and stirrup braces, reduced pain and improved gait parameters compared to Tubigrip. Overall, no significant increase in complications was observed with early mobilization strategies. **Conclusion**: Individualized rehabilitation plans incorporating early mobilization, compression therapy, and supportive devices can optimize functional recovery after ankle fracture surgery. Future research should focus on long-term outcomes and cost-effectiveness of these strategies.

Keywords: ankle fracture, rehabilitation, weight-bearing, compression therapy, active controlled motion, functional recovery

INTRODUCTION

Ankle fractures are among the most prevalent fractures worldwide and the most common type in the lower limbs, significantly impacting patient mobility and quality of life.[1,2] These fractures are categorized into unimalleolar, bimalleolar, and trimalleolar fractures, depending on the number of malleoli involved. Among these, trimalleolar ankle fractures (TAF), involving the posterior malleolus along with bimalleolar fractures, represent the most complex type.[3] Although TAF accounts for only about 7% of all ankle fractures, its complexity often poses substantial challenges in management. These injuries frequently result from high-energy trauma and are more commonly observed in females, with underlying factors such as osteopenia or osteoporosis potentially contributing to their higher susceptibility.[3,4]

Management of ankle fractures typically begins with surgical intervention, most commonly open reduction and internal fixation (ORIF), aimed at restoring anatomical alignment and joint stability.[5,6] Despite advancements in surgical techniques, achieving optimal functional recovery remains a challenge. Post-operative complications, including joint stiffness, traumatic arthritis, walking instability, and deformities, are not uncommon and can lead to prolonged disability if not addressed effectively. As a result, post-operative rehabilitation is critical in restoring strength, flexibility, and functionality to the affected ankle while minimizing long-term sequelae. [7,8]

Rehabilitation protocols for ankle fractures encompass a variety of interventions tailored to the patient's specific needs and recovery progress. Core components include exercises to improve joint mobility, muscle strength, balance, and proprioception.[9] Joint mobilization techniques, such as the Mulligan concept of mobilization with movement (MWM), have shown promise in enhancing range of motion and reducing pain. Furthermore, advanced therapies, including

neuromuscular electrical stimulation and robotic-assisted rehabilitation, have been introduced to augment traditional approaches and accelerate recovery. Emerging technologies, such as dynamic bracing systems and biological agents that enhance tissue healing, have further expanded the therapeutic options, providing additional or complementary benefits in rehabilitation.[10,11]

Despite the wide range of available strategies, variability exists in their effectiveness, with no universal consensus on the optimal approach for post-operative care. Tailoring rehabilitation programs to individual needs, based on factors such as fracture type, surgical outcomes, and patient-specific challenges, is crucial to maximizing recovery. This systematic review aims to evaluate and compare various rehabilitation strategies following ankle fracture surgeries. By synthesizing current evidence, the review seeks to provide actionable insights into the most effective approaches for optimizing recovery, minimizing complications, and enhancing overall functional outcomes in patients with ankle fractures.

METHODS

Protocol

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, consistency, and reproducibility. The protocol is designed to systematically review and analyze rehabilitation strategies and outcomes following ankle fracture surgery.

Criteria for Eligibility

This review will include studies published between 2004 and 2024 that investigate rehabilitation interventions for patients who have undergone surgical fixation for ankle fractures. Eligible studies must focus on humans and discuss rehabilitation techniques, their effectiveness, and patient outcomes related to mobility, strength, pain management, and functional recovery. The inclusion criteria are as follows:

- **Study Types**: Clinical trials, cohort studies, case-control studies, and observational studies.

- **Population**: Patients with ankle fractures who underwent surgical intervention.
- **Interventions**: Rehabilitation strategies, including physical therapy, joint mobilization, weight-bearing exercises, neuromuscular electrical stimulation, and other innovative approaches.
- **Outcomes**: Measures of functional recovery, range of motion, pain reduction, return to activity, and long-term complications.

Exclusion criteria include:

- Non-peer-reviewed articles, reviews, expert opinions, conference abstracts, animal studies, in vitro experiments, or studies lacking detailed methodology relevant to rehabilitation.

Search Strategy

A comprehensive literature search will be conducted in electronic databases, including PubMed, Embase, ScienceDirect, Cochrane Library, and Web of Science. The search will focus on key terms related to ankle fractures and rehabilitation.

Primary search terms include:

- "Ankle Fracture," "Trimalleolar Fracture," "Rehabilitation," "Physical Therapy," and "Post-Surgical Recovery."

Secondary terms include:

- "Range of Motion," "Weight-Bearing Exercises," "Joint Mobilization," "Electrical Stimulation," and "Patient Outcomes."

Example search string: ("Ankle Fracture" OR "Trimalleolar Fracture") AND ("Rehabilitation" OR "Physical Therapy") AND ("Post-Surgical Recovery" OR "Functional Outcomes"). Boolean operators (AND, OR) will be used for precise searches.

Data Retrieval

The review will involve a two-step process:

1. Screening of titles and abstracts for relevance to the study's objectives.
2. Full-text review of articles that meet inclusion criteria.

Data extraction will focus on study characteristics, patient demographics, rehabilitation methods, intervention timelines, and outcomes such as recovery rates, pain levels, and complication rates.

Quality Assessment and Data Synthesis

Two independent reviewers will evaluate the methodological quality of the included studies based on factors such as study design, sample size, intervention details, and outcome reliability. Disagreements

will be resolved through discussion or by consulting a third reviewer.

A qualitative analysis will synthesize findings on various rehabilitation approaches, highlighting their impact on functional recovery and patient outcomes. If sufficient homogeneity exists, a meta-analysis will be conducted to quantify the effectiveness of specific rehabilitation strategies. Subgroup analyses may explore variations based on age, type of fracture, and the timing of rehabilitation. This structured approach aims to provide a comprehensive overview of rehabilitation strategies following ankle fracture surgery and identify the most effective methods for enhancing patient recovery.

Table 1. Search Strategy and Results

Database	Search Strategy	Hits
PubMed	("Ankle Fracture" OR "Trimalleolar Fracture") AND ("Rehabilitation" OR "Physical Therapy") AND ("Outcomes" OR "Recovery")	245
ScienceDirect	"Ankle Fracture" AND "Rehabilitation" AND "Physical Therapy" AND "Functional Recovery"	210
Embase	'Ankle Fracture' OR 'Trimalleolar Fracture' AND 'Rehabilitation' OR 'Physical Therapy' AND 'Outcomes'	190
Cochrane Library	"Ankle Fracture" AND "Rehabilitation" AND "Post-Surgical Recovery" AND "Functional Outcomes"	180
Web of Science	"Ankle Fracture" AND "Rehabilitation" AND "Physical Therapy" AND "Post-Surgical Recovery"	220

This table summarizes the search strategies employed across multiple databases to ensure comprehensive retrieval of relevant literature for the systematic review.

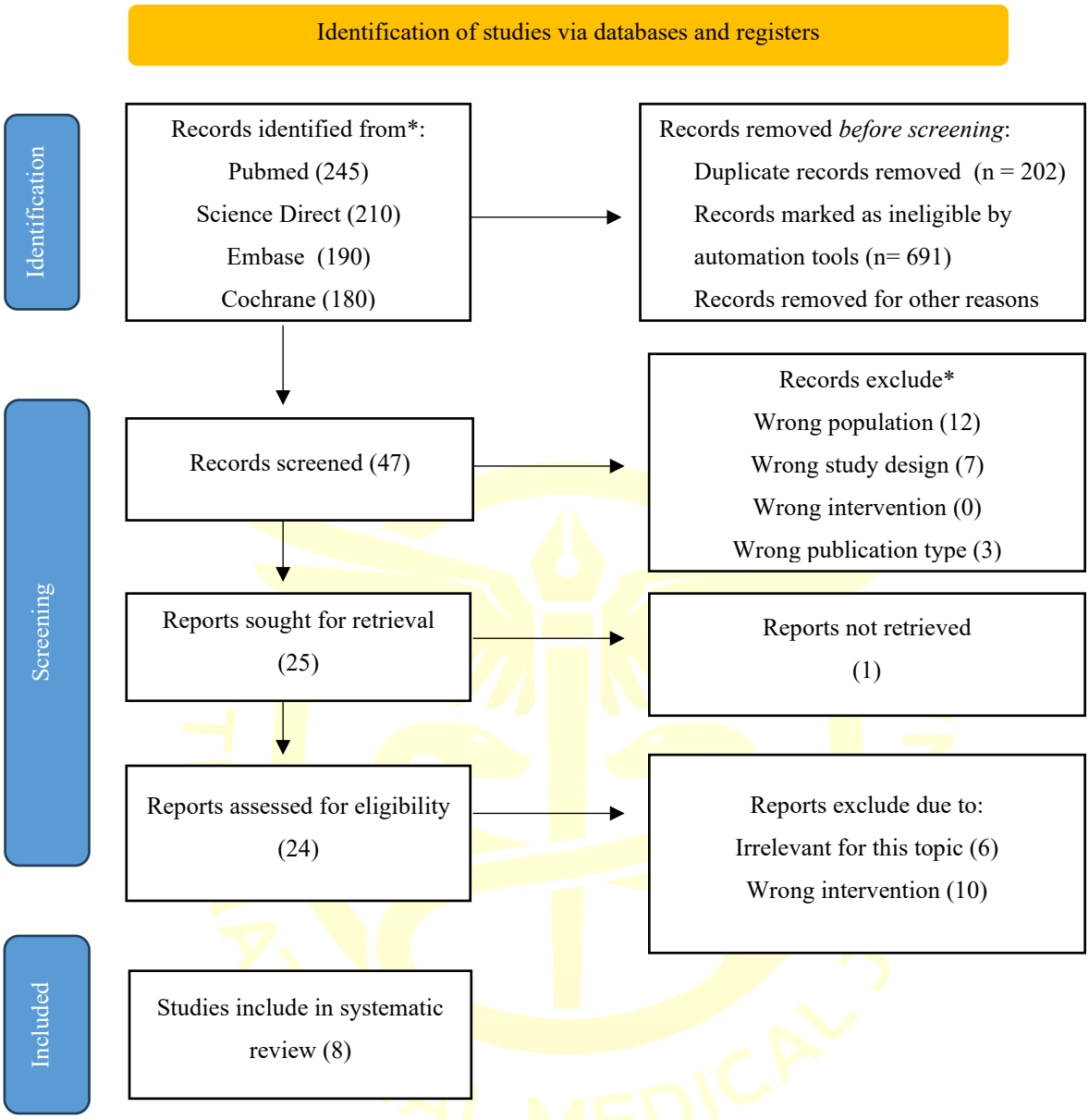

Figure 1. PRISMA Flowchart for Study Selection

RESULT

Our research team first gathered publications from reputable sources such as Science Direct, PubMed, and SagePub. After a thorough three-level screening procedure, only eight papers were determined to be directly relevant to our ongoing systematic evaluation. Following that, these sections were picked for additional research and a close reading of the entire manuscript. The material that was evaluated for this analysis is compiled in Table 2 for ease of view.

Table 2. The literature included in this study

Author	Origin	Method	Sample Size	Result
Moseley AM et al., 2015.[12]	Australia	The EXACT trial was a pragmatic, randomized clinical trial	Of 571 eligible patients, 357 chose not to participate and 214 were allocated to rehabilitation (n = 106) or advice alone (n = 108), with 194 (91%) followed up at 1 month, 173 (81%) at 3 months, and 170 (79%) at 6 months.	Mean activity limitation and quality of life at baseline were 30.1 (SD, 12.5) and 0.51 (SD, 0.24), respectively, for advice and 30.2 (SD, 13.2) and 0.54 (SD, 0.24) for rehabilitation, increasing to 64.3 (SD, 13.5) and 0.85 (SD, 0.17) for advice vs 64.3 (SD, 15.1) and 0.85 (SD, 0.20) for rehabilitation at 3 months. Rehabilitation was not more effective than advice for activity limitation (mean effect at 3 months, 0.4 [95% CI, -3.3 to 4.1]) or quality of life (-0.01 [95% CI, -0.06 to 0.04]). Treatment effects were not moderated by fracture severity or age and sex.
Sultan et al., 2014. [13]	UK	randomised controlled trial.	A total of 90 patients with a mean age of 47 years	Compression using AIS reduced swelling of the ankle at all time points and improved the mean OMAS score at six months to 98 (95% confidence interval (CI) 96 to 99) compared with a mean of 67 (95% CI 62 to 73) for the Tubigrip group ($p < 0.001$). The mean AOFAS and SF-12v2 scores at six months were also significantly improved by compression. Of 86 patients with duplex imaging at four weeks, five (12%) of 43 in the AIS group and ten (23%) of 43 in the Tubigrip group developed a DVT ($p = 0.26$).

Albin et al., 2019. [14]	China	Multisite, double-blind randomized clinical trial.	72 patients.	There were no significant differences between the manual therapy and control groups for range of motion, gait, or balance outcomes. There was a significant difference from baseline to the final follow-up in resting gastrocnemius muscle stiffness between the manual therapy and control groups (-47.9 N/m; 95% confidence interval: -86.1, -9.8; P = .01). There was no change in muscle stiffness for the manual therapy group between baseline and final follow-up, whereas muscle stiffness increased in the control group by 6.4%.
Keene et al., 2016. [15]	Sweden	A randomized crossover trial.	Participants were 18 adults, 6 weeks after internal fixation for transsyndesmotic/infrasyndesmotic fracture, in a major trauma center in the UK	Participants (mean ± SD age, 47 ± 14 years) included 8 women and 10 men, 6 weeks after surgical internal fixation for ankle fracture. Single-limb support time asymmetry reduced by 3% (95% confidence interval [CI]: 0%, 6%; P = .02) in the stirrup brace and by 5% (95% CI: 2%, 7%; P = .001) in the walker boot compared with Tubigrip. Step width was 1.2 cm (95% CI: 0.6, 1.7; P<.001) wider in the walker boot than in Tubigrip. Self-reported pain was lower in the walker boot (5/100) and in the stirrup brace (13/100) compared to the Tubigrip (18/100, P = .03). No significant differences were found in the effects of the supports on step-length asymmetry between the walker boot or stirrup brace and Tubigrip.

Jansen et al., 2018. [16]	German	Prospective randomized controlled trial.	A total of 50 patients with unstable ankle fractures and the need for partial weight-bearing for six weeks.	Range of motion was better in the ACM group at six weeks (mean 49° ± 11.1° vs. 41.3° ± 8.1°). Questionnaires revealed better outcome after six weeks in the VAS FA (56 ± 13.7 vs. 40.6 ± 10.5), Mazur score (64.4 ± 12.3 vs. 56.7 ± 11) and AOFAS score (71.2 ± 12 vs. 63.6 ± 8.7) (P > 0.02 for all). Better outcome after 12 weeks in all questionnaires (VAS FA, 77.7 ± 13.8 vs. 61.4 ± 16.3; Philip score, 79.1 ± 10.9 vs. 60.1 ± 21.7; Mazur score, 83.9 ± 10.7 vs. 73.1 ± 14.1; AOFAS score, 87.5 ± 7.9 vs. 75.2 ± 11.7) (P < 0.01 for all). Pressure balance was better under the midfoot region after 12 weeks in the ACM group (Δ P 4.4 N vs. 34.0 N; P = 0.01). The ACM group had an earlier return to work after 10.5 (range, 3-17) versus 14.7 (range, 9-26) weeks (P = 0.02).
Bretherton et al., 2024. [17]	UK	pragmatic, multicentre, randomised, non-inferiority trial.	561 participants (aged ≥18 years) who received acute surgery for an unstable ankle fracture in 23 UK National Health Service (NHS) hospitals who were assigned to either a delayed weight-bearing (n=280) or an early weight-bearing rehabilitation strategy (n=281).	4 months after randomisation, the mean OMAS score was 65·9 in the early weight-bearing and 61·2 in the delayed weight-bearing group and adjusted mean difference was 4·47 (95% CI 0·58 to 8·37, p=0·024; superiority testing adjusted difference 4·42, 95% CI 0·53 to 8·32, p=0·026) in favour of early weight-bearing. 46 (16%) participants in the early weight-bearing group and 39 (14%) in the delayed weight-bearing group had one or more complications (adjusted odds ratio 1·18, 95% CI 0·80 to 1·75, p=0·40). The mean costs from the perspective of the NHS and personal social services in the early and delayed weight-bearing groups were £725 and £785, respectively (mean difference -£60 [95% CI -342 to 232]). The probability that early weight-bearing is cost-effective exceeded 80%.
Smeeing et al., 2020. [18]	Netherland	multicentered randomized controlled trial	A total of 115 patients were randomized.	The O'Brien-Fleming threshold for statistical significance for this interim analysis was 0.008 at 12

		was conducted in patients ranging from 18 to 65 years of age without severe comorbidities.		weeks. The OMAS was higher in the unprotected weight-bearing group after 6 weeks c(61.2 ± 19.0) compared to the protected weight-bearing (51.8 ± 20.4) and unprotected non-weight-bearing groups (45.8 ± 22.4) (p = 0.011). All other follow-up time points did not show significant differences between the groups. Unprotected weight-bearing showed a significant earlier return to work (p = 0.028) and earlier return to sports (p = 0.005). There were no differences in the quality of life scores or number of complications.
Schubert et al., 2020. [19]	US	Retrospective chart analysis.	Fifty patients with unstable rotational-type ankle fractures were treated operatively with subsequent immobilization in a below-the-knee cast for 2 weeks and were then randomly allocated to 2 groups.	Patients in the early weightbearing group had higher mean EQ-5D VAS scores at a 6-week follow-up (P = .014) of 77 ± 14 compared to 66 ± 15 for late mobilization. No difference was found at other follow-up points or between groups for physician-based outcome measures. At 26 weeks postoperatively, mean Olerud and Molander ankle scores were similar at 84 ± 16 and 81 ± 17 for mobilization at 2 and 6 weeks postoperation, respectively.

Table 2. Critical appraisal of Study

Parameters	Moseley AM et al., 2015	Sultan et al., 2014	Albin et al., 2019	Keene et al., 2016	Jansen et al., 2018	Bretherton et al., 2024	Smeeing et al., 2020	Schubert et al., 2020
1. Bias related to temporal precedence								
Is it clear in the study what is the "cause" and what is the "effect" (ie, there is no confusion about which variable comes first)?	Cause and effect clearly defined; no temporal confusion.	Temporal relationship between cause and effect was clear.	Clear cause (manual therapy) and effect (outcomes) relationship.	Cause and effect clearly delineated.	Clear delineation of intervention and outcomes.	Clear relationship between rehabilitation strategy and outcomes.	Clear relationship between weight-bearing strategy and outcomes.	Temporal relationship between intervention and outcomes clear.
2. Bias related to selection and allocation								
Was there a control group?	Randomized control with allocation described.	Randomized control group; participants were randomized.	Randomized control design included a control group.	Randomized crossover design minimized allocation bias.	Randomized design with a control group.	Randomized multicenter trial with defined groups.	Randomized control ensured comparability.	Retrospective chart review; groups allocated based on timing.
3. Bias related to confounding factors								
Were participants included in any comparisons similar?	Participants were matched and similar at baseline.	Groups were comparable at baseline.	Groups were similar at baseline; no confounding noted.	Crossover design minimized confounding; groups balanced.	Baseline characteristics matched between groups.	Baseline characteristics were similar across groups.	Confounding was controlled; baseline characteristics matched.	Baseline characteristics similar; retrospective confounding possible.

4. Bias related to administration of intervention/exposure								
Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	Similar care provided except for the intervention.	Intervention was standardized; care was consistent.	Manual therapy standardized; control group received standard care.	Interventions standardized across groups.	Care was consistent except for the treatment under study.	Groups received similar care except for intervention.	Comparable care provided to all groups.	Treatment protocols standardized across groups.
5. Bias related to assessment, detection, and measurement of the outcome								
Were there multiple measurements of the outcome, both pre and post the intervention/exposure?	Reliable pre- and post-intervention measures used.	Outcome measures consistent and reliable.	Reliable tools used to measure outcomes consistently.	Validated tools used for consistent outcome measurement.	Reliable and validated outcome measures applied consistently.	Reliable measures for both effectiveness and cost analyzed.	Validated tools used consistently.	Consistent application of validated outcome tools.
Were the outcomes of participants included in any comparisons measured in the same way?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were outcomes measured in a reliable way?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

6. Bias related to participant retention								
Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed?	Follow-up incomplete (79%), but reasons analyzed.	Follow-up data were complete; dropouts well-described.	High completion rates; minimal dropout differences.	High retention rates; attrition bias minimal.	Follow-up data complete; minimal dropout.	Follow-up completion was high; dropout differences not significant.	Retention rates high; dropouts well-explained.	Follow-up rates high; dropout not a concern.
7. Statistical conclusion validity								
Was appropriate statistical analysis used?	Appropriate statistical methods with confidence intervals.	Statistical analysis was robust; p-values provided.	Statistical tests robust; differences and interactions explained.	Paired analysis for crossover was appropriate.	Statistical analysis clear with p-values for outcomes.	Statistical methods robust; cost and outcome measures detailed.	Appropriate statistical tests applied.	Statistical analysis described and appropriate.

DISCUSSION

The findings from the included studies highlight the diverse rehabilitation strategies following surgical treatment for ankle fractures, each offering varying degrees of efficacy in improving patient outcomes. The EXACT trial by Moseley et al. demonstrated that rehabilitation was not significantly more effective than simple advice in reducing activity limitations or enhancing quality of life in patients post-ankle fracture. Despite the large sample size and high follow-up rates, the lack of notable differences between the intervention groups suggests that the value of intensive rehabilitation may be limited in certain cases, especially when basic mobility advice suffices. [12]

Compression therapy, as explored by Sultan et al., appears promising. Compression stockings not only reduced ankle swelling but also significantly improved functional outcomes, including the Olerud-Molander Ankle Score (OMAS), AOFAS, and SF-12v2 scores. The reduction in deep vein thrombosis (DVT) incidence, though not statistically significant, underscores the potential secondary benefits of compression. This study advocates for compression as a cost-effective adjunct in post-operative management.[13] Manual therapy, examined by Albin et al., showed minimal impact on range of motion, gait, or balance outcomes but significantly reduced resting muscle stiffness. The findings suggest that manual therapy may have a role in preventing muscle stiffness postoperatively, even if its broader impact on functional outcomes is less pronounced.[14]

The randomized crossover trial by Keene et al. assessed the immediate effects of different ankle supports. Both stirrup braces and walker boots improved single-limb support time asymmetry and reduced self-reported pain compared to standard Tubigrip. However, no significant differences in step-length asymmetry were observed. These findings emphasize the potential of

tailored ankle supports to enhance mobility and reduce discomfort in the early rehabilitation phase.[15] Jansen et al. provided compelling evidence favoring active controlled motion (ACM). Patients in the ACM group demonstrated superior outcomes in range of motion, functional scores, and time to return to work compared to conventional rehabilitation. This highlights the importance of early mobilization in optimizing recovery and functional outcomes. [16]

Weight-bearing strategies, explored in several studies, revealed nuanced findings. Bretherton et al. showed that early weight-bearing led to slightly better functional outcomes (OMAS scores) and was more cost-effective than delayed weight-bearing, without increasing complication rates.[17] Similarly, Smeeing et al. found that unprotected weight-bearing expedited return to work and sports compared to other strategies. [18] Schubert et al. also noted higher EQ-5D VAS scores with early mobilization, suggesting better health-related quality of life at earlier follow-ups, although long-term outcomes were comparable between early and late mobilization. [19] Overall, the evidence underscores the importance of individualized rehabilitation approaches. While early mobilization and weight-bearing strategies generally yield favorable outcomes, the choice of intervention should consider patient-specific factors, such as fracture severity, comorbidities, and recovery goals. Additionally, cost-effective strategies, such as compression therapy and tailored supports, offer practical benefits for enhancing recovery and minimizing complications. Further research is warranted to explore the interplay between various rehabilitation modalities and their long-term impact on functional recovery and quality of life.[20-22]

The importance of early controlled motion was emphasized by Jansen et al., who reported significant improvements in range of motion, functional scores, and return-to-work timelines in patients undergoing active controlled motion (ACM) compared to traditional partial weight-bearing protocols.[16] This aligns with the growing evidence

favoring early mobilization strategies to expedite recovery. While the studies provided robust evidence, some limitations warrant discussion. Heterogeneity in patient populations, fracture severity, and rehabilitation protocols makes direct comparison challenging. Furthermore, differences in follow-up durations limit the ability to assess long-term outcomes consistently.[23,24] Future research should prioritize standardized protocols and larger multicenter trials to validate these findings further. Overall, this review highlights the evolving landscape of ankle fracture management, emphasizing the balance between early mobilization, patient comfort, and resource utilization. Tailored rehabilitation strategies, informed by evidence, can optimize recovery while minimizing complications.

CONSCLUSION

This systematic review highlights the diverse rehabilitation strategies employed after surgical treatment for ankle fractures, each with distinct implications for patient outcomes. Early weight-bearing and active controlled motion consistently demonstrated benefits in enhancing functional recovery, expediting return to work and activities, and improving patient-reported outcomes without increasing complication rates. Compression therapy effectively reduced swelling and improved functional scores, while tailored ankle supports like walker boots and stirrup braces reduced pain and asymmetry during gait. Despite the potential benefits of some interventions, the evidence suggests that intensive rehabilitation may not always be necessary, as simple advice can yield comparable outcomes in certain cases. Individualized rehabilitation plans, incorporating patient-specific needs, fracture severity, and cost-effectiveness, are essential for optimizing recovery. Further studies are recommended to refine these strategies and investigate their long-term impact on functional recovery and quality of life.

DISCLOSURE STATEMENT

- Disclosure Statement : The authors have no conflicts of Interest to declare

- Funding Sources : None
- Acknowledgements : -
- Author Contribution : All authors discussed and contributed the final content for journal submission and publication

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