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Review

Management of non-union of rib fractures secondary to trauma: A scoping review

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ABSTRACT

Objective: Rib fracture non-union is an uncommon complication of traumatic rib fractures. Our objective was to perform a scoping review of the literature for the management of rib fracture non-union. This included analysis of the variations in surgical technique, complications experienced, and reported outcomes.
Methods: We conducted a scoping review and searched databases (MEDLINE, CINAHL, and Embase). We performed abstract and full-text screening, and abstracted data related to pre-operative assessment, surgical technique, complications, and reported outcome measures.
Results: We included 29 articles of which 19 were case reports and 10 were case series. The data quality was generally heterogeneous. The studies included 229 patients and the commonest symptoms of rib fracture non-union included chest pain, clicking, dyspnea and deformities. The patients underwent surgical management of rib fracture non-union (excluding first rib fractures) using various techniques. The majority used surgical stabilization of rib fracture with or without a graft. The reported outcomes were inconsistent between studies, but showed high rates of union (>94 %), reduction in reported VAS scores, and improved return to work when included. Implant failure occurred in 10 % of the 229 total patients reported in our studies, the re-operation rate was 13 %, and the overall complication rate was 27 %.
Conclusion: Surgical management of rib fracture non-union often involving locking plates and screws with or without a graft has been shown in several case reports and series as an effective treatment with acceptable implant failure and complication rates. Surgical management is therefore a viable option for symptomatic patients. Further research is required to determine optimal management strategies that further reduce surgical complications for these patients.

Introduction

Non-union of rib fractures is an uncommon complication that occurs when the fracture has incompletely healed 3–6 months after injury [1,2]. These can be symptomatic, causing instability with mechanical symptoms (clicking and motion), chronic pain, and dyspnea on exertion [3]. The rate of non-union is estimated to be between 5 and 10 %, but is not well studied for rib fractures [4,5]. In a recent meta-analysis of patients who previously underwent acute surgical stabilization of rib fractures (SSRF), 1.3 % had non-union [6]. Suspected risk factors include smoking, malnourishment, NSAIDs or steroids, diabetes, and deficiency of vitamin D [4].

Historically, surgical management of symptomatic rib fracture non-union involved surgical resection of the affected ribs. Despite

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continued research into the indications for SSRF in severe rib fracture and flail chest, there is limited evidence investigating the management of rib fracture non-union. A few case reports and cross-sectional case series describe the operative management for symptomatic non-unions and there are no systematic or scoping reviews into the management of rib fracture non-union.

Therefore, our objective was to perform a scoping review of the management of rib fracture non-union following traumatic injuries. The key questions (KQs) guiding the conduct of this scoping review are outlined below:

KQ 1: What are the current techniques employed to manage non-union of rib fractures?

KQ 2: What is the impact of these techniques on outcomes including but not limited to radiographic union, pain reduction, complications, length of stay and return to work?

Methods

We performed a systematic literature search to identify studies related to non-union of traumatic rib fractures following the Joanna Briggs Institute methodology for scoping reviews, and adhered to the checklist items in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) and PRISMA 2020 statement (Appendix 1) [7,8].

Search strategy

A comprehensive search strategy was conducted by an experienced health information specialist (TK) in collaboration with the rest of the research team. The search was peer-reviewed by another senior information specialist using the Peer Review of Electronic Search Strategies (PRESS) Checklist. Articles were searched from 1980 onwards from inception to present, using the following databases: MEDLINE (Ovid), CINAHL (EBSCO), and Embase (Ovid). This search was initially performed on June 20, 2022, and updated on May 17, 2023, to reflect the new articles published during the year. We also reviewed the reference lists of the reviewed articles for any missed articles that meet our inclusion criteria. The search strategy for one database is attached as Appendix 2.

Eligibility

We included studies that described the incidence or management of non-union of traumatic rib fractures (Table 1). Articles related to the management of acute fractures were excluded. Articles related solely to non-union fractures in the first rib were excluded given their unique mechanism and management. Also excluded were articles related to non-traumatic causes of rib fracture non-union, such as pathologic fractures secondary to malignancy, other metabolic diseases, or medical disorders. We included all publication types except abstracts with no corresponding full paper, narrative reviews, editorials, grey literature, pre-prints, and conference proceedings. Studies published prior to 1980 were excluded and non-English studies were excluded.

Data analysis

The search results and full-texts were uploaded to Covidence which was used for title and abstract screening and full-text article screening by two independent reviewers (AN and CAM). Conflicts were resolved by consensus among the reviewers, with any remaining disputes by a third-party reviewer (DG) if required. Data abstraction was performed by two independent abstractors (AN and CAM). Data abstraction was performed for each article by both members and conflicts discussed until a consensus was reached. The detailed items of data abstraction are included in Table 2. The results of the study are presented as a narrative synthesis. The data charting, extraction, and sorting enabled us to identify themes and results to answer the review's key questions.

Table 1
Eligibility criteria for KQ1 and KQ2.

	Inclusion criteria	Exclusion criteria
Population	All adults (>16 years) with a non-union of rib fracture	N/A
Concept/ Intervention	All treatment strategies employed to manage traumatic non-union fractures	Treatment strategies targeting acute rib fractures or non-union of first rib fracture Non-unions secondary to non-traumatic causes of rib fracture non-union, such as pathologic fractures secondary to malignancy, other metabolic diseases, or medical disorders
Context (Setting)	Trauma centers/ hospitals at all levels	N/A
Study designs	Any experimental or observational study design (e.g., RCTs, quasi-randomized, controlled clinical trials, cohort studies, case-control, cross-sectional, time-series, case series and case reports) and systematic reviews. Any relevant grey literature sources (e.g., government reports) and preprints.	Narrative reviews, editorials, news articles, commentaries, letters, and conference proceedings.
Language	English	N/A
Dates of publication	Studies beyond 1980-	N/A

Quality appraisal

We performed a quality appraisal of our included case reports and case series using the methodological quality assessment tool proposed by Murad et al. [9] We chose this tool for its efficiency and adaptability, enabling a concise yet comprehensive appraisal of methodological quality tailored to our papers. This framework provided a structured approach for examining the robustness of the case series using four key

Table 2
Items for data abstraction.

Category	Data items
Study identification	- First author - Year - Country
Publication type	- Type of study/article (e.g., RCT, cohort, case-control, cross-sectional, case-series, or case-report)
Patients characteristics	- Type of population studied - Number of patients studied - Mean age, sex, BMI, smoking history - Past medical history - Definition of non-union of rib fractures - Mechanism of trauma - Time to presentation - Indication for surgery
Management details	- Management technique - Investigations -CXR, CT, MRI, 3D reconstruction - Bilateral vs unilateral - Grafting vs not - Osteosynthesis technique - Hardware removal vs not - Chest tube placement vs not
Outcomes	- Total complications - Revision surgery - Pain reduction - LOS - Return to work time - Radiographic non-union
Key findings	- Overall study findings

domains: selection, ascertainment (of exposure and outcome), causality, and reporting and covers important components of the CARE guidelines (for CAse REports). [10]

For selection, we checked for any biases in enrolment. In ascertainment, we evaluated whether the exposure and outcomes were adequately determined and confirmed. For causality, we considered if alternative causes that could explain the observations had been adequately ruled out. Lastly, in reporting, we ensured that cases were described sufficiently to allow reproducibility.

The tool was modified to remove two questions relevant to adverse drug events, as they did not apply to our case series. A final quality assessment was assigned as criteria "met" or "not met," reflecting the reviewer's judgment on the study's internal validity.

Results

We identified 351 abstracts in the database search after removing duplicates. Of these articles, 47 met the criteria for full-text screening (Fig. 1). Full-text screening excluded 18 articles (10 due to being related to non-union of first rib fractures, and 8 were unrelated to the management of non-united rib fractures). Therefore, a total of 29 articles were included for data abstraction. Of these, 19 were case reports, and 10 were cross-sectional studies. Seventeen studies (10 case reports and 7 case series) were from US medical centers, five studies (2 case series and 3 case reports) were from the Netherlands, two were from the UK, and two were from Switzerland. Turkey, Japan, and Korea reported one study each.

In total, the included studies describe 229 patients who underwent surgical management of rib fracture non-union (excluding first rib fractures). Of note, a paper by Ogunleye et al. extended their analysis to 25 patients of a previously published 10-patient case series. Most papers comprised of multidisciplinary authors. However, upon a first author designation analysis, we found that 15/29 (51.7 %) papers were published by general and trauma surgeons, 9/29 (31 %) by orthopedic surgeons, and 5/29 (17.2 %) by thoracic & cardiovascular surgeons. We have attached an excel file with the extracted data for the papers we included in our review as Appendix 3.

Definition of rib fracture non-union

A definition for symptomatic rib fracture non-union was provided in all articles containing case series. While there is no standardized definition for rib fractures non-union, the most frequent criteria used among the case series was the diagnosis (clinical and radiographic) of one or more rib fractures non-unions at least 3 months after the initial trauma or SSRF, though 2 articles (25 %) of the case series defined it as >6 months. The radiographic tests used to determine non-union included x-ray, CT, MRI imaging, or 3D reconstruction and the clinical factors utilized included, persistent pain, rib instability, and clicking sounds.

Rate of rib fracture non-union

The rate of rib fracture non-union was not included in the majority of the articles; however, in one study by Minervini et al. they reported operating on 19 patients with symptomatic rib fracture non-union of the 1142 patients with rib fractures managed at their center study period,

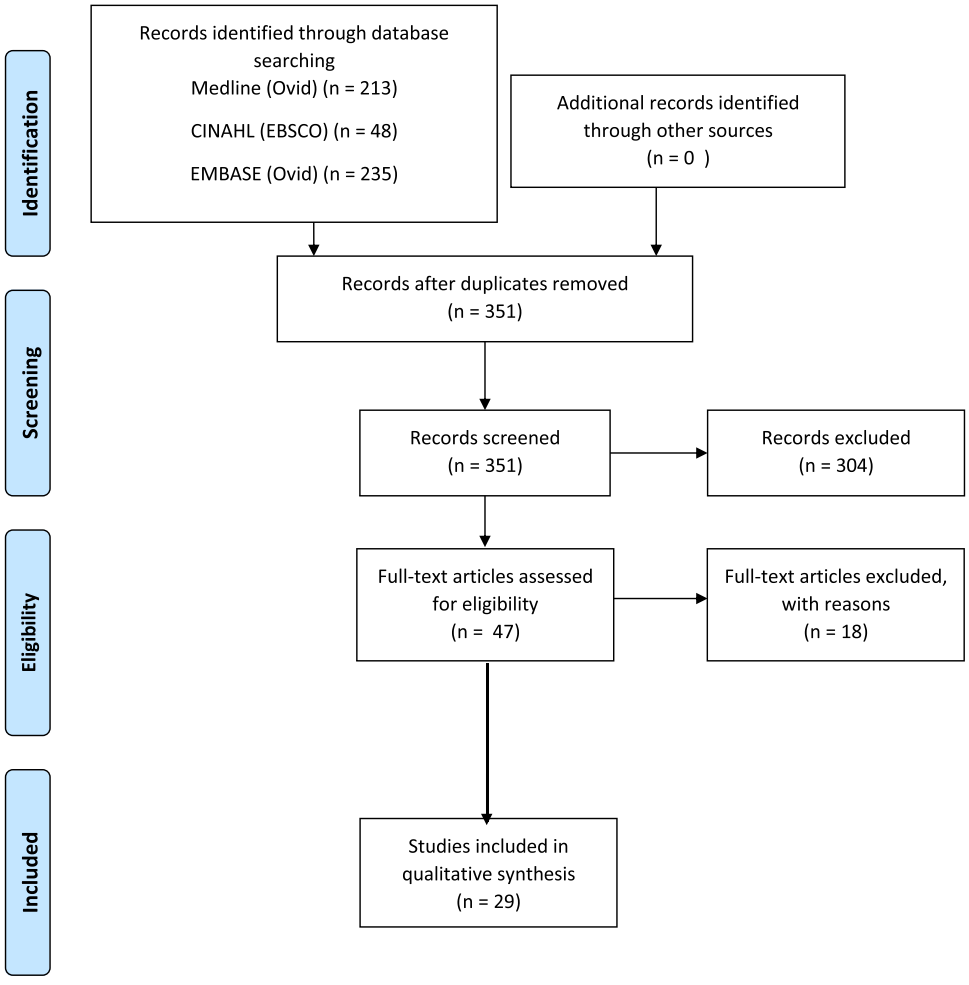

Fig. 1. PRISMA Flowchart of screened and included studies.

for a rate of 1.65 %. [11]

Time to surgery and indications for surgery

Most studies reported the time interval between the initial injury and operative management of non-union. The range was quite broad, with a minimum reporting timing of 2 months ranging to several years after their initial trauma. The median time to surgery was frequently reported as between 12 and 24 months, indicating a generally prolonged delay between their initial trauma and attempt at definitive management for these patients.

The indication for surgery in all cases was symptomatic non-union, with patients typically having imaging findings of non-union on X-ray, CT scan, or MRI. Some articles documented repeated imaging showing no improvement over time.

Symptoms

In our included papers where symptoms were specifically described, the predominant pre-treatment non-union symptom was chronic pain –93 % (68/73). This was followed by clicking sensation –35 % (26/73), dyspnea on exertion –10.9 % (8/73) and chest deformities –9.5 % (7/73). Other symptoms reported included tenderness to palpation and nerve tingling. Symptoms typically worsened with exertion and deep breathing impacting patients' ability to do daily activities or work.

Non-operative techniques

Many studies for patients with symptomatic non-union reported patients first undergoing non-operative management with analgesia, often involving pain specialists prior to their surgery. Management techniques for intercostal nerve pain or neuralgia such as cryoablation of intercostal nerve, [12,13], radiofrequency ablation [14], and neurolytic intercostal nerve block with phenol [15] have not been investigated for

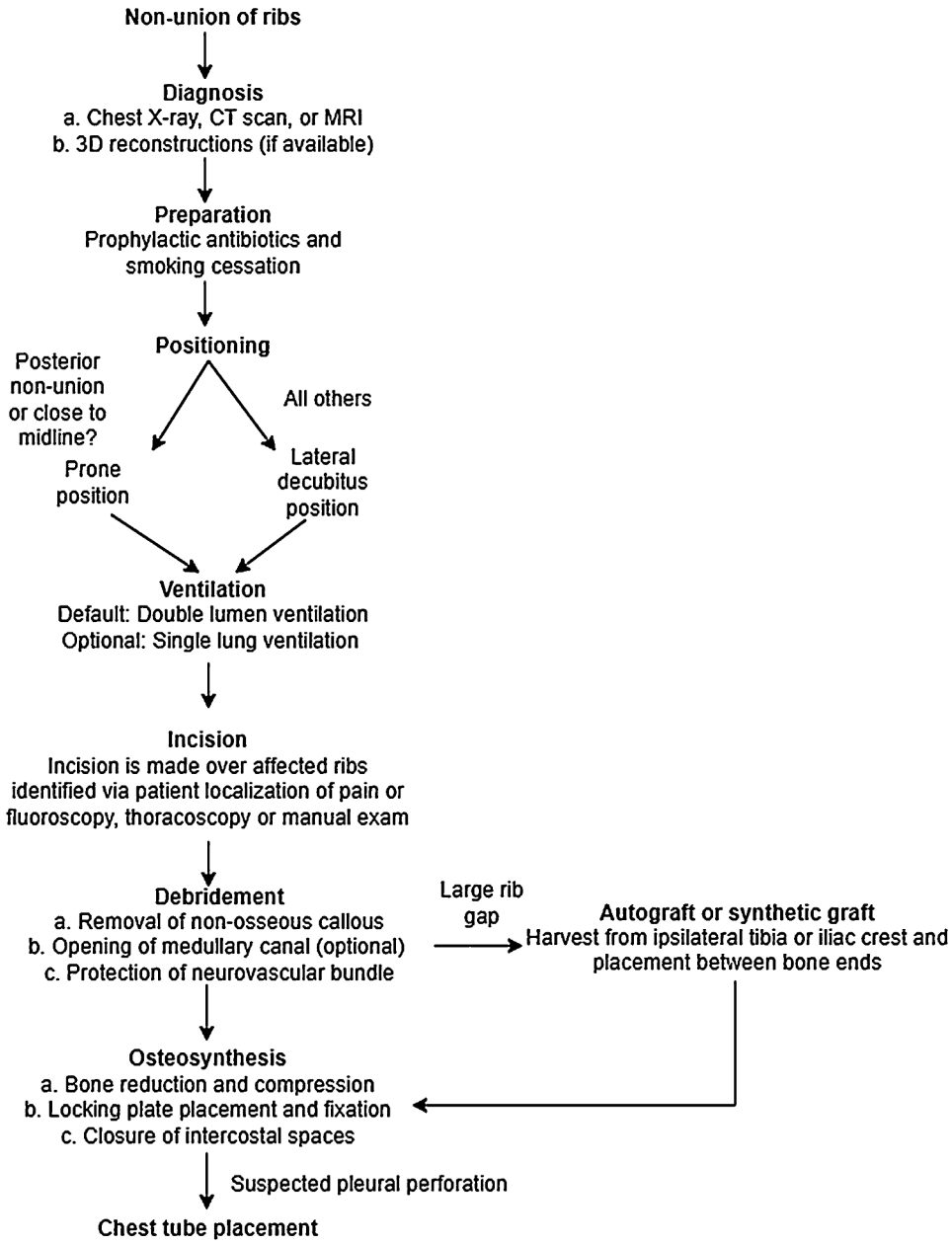

Fig. 2. A synthesis of common steps in the management of non-union of rib fractures.

rib fracture non-union. In a retrospective case series by Gauger et al. all patients first underwent a minimum 3-month trial of a bone stimulator. However, success was very limited, with only 1 of 10 patients healing 1 out of 3 non-united rib fractures. [16]

Operative techniques

While there were differences between the management of rib fracture non-unions across the papers, a synthesis of common steps across papers has been presented in Fig. 2.

Planning

Three of the eight cross-sectional studies used chest X-rays, CT scans, or MRI for pre-operative planning [11,17,18]. Five centers additionally incorporated 3D reconstructions to localize non-unions and to map the surgery [1,2,16,19,20]. Patients were asked to point to the most painful regions in the chest, which were then carefully palpated, matched with 3D visualizations, and marked by the surgeon pre-operatively.

Incision

Minervini et al. also used a diagnostic thoracoscopy to facilitate identification of the non-union [11]. Gauger et al. used fluoroscopy and manual examination to correlate the site of non-union with the point of maximal pain [16]. For a single rib non-union, the incision was made directly over the affected rib. If multiple rib non-unions were involved, the incision was centered over the affected ribs.

Debridement and SSRF

Debridement of callous, fibrous, and atrophic tissue was an important step for the management of non-unions in most studies. Debridement was done to ensure there is a minimal gap between rib ends but also to allow healthier bleeding bones to contact firmly with each other to promote bone healing. Ogunleye et al. also considered opening the medullary canal of the rib to draw the endosteal blood supply to the reconstructed site [19]. When debriding, it is important to protect the intercostal neurovascular bundle at the inferior aspect of the rib. A few groups resected only the superior aspect of the non-union site to minimize the risk of injury to the neurovascular bundle [11,16,19]. One case report describes excision of heterotopic ossifications (HO) forming vertical osseous bridges between ribs with fracture non-union [21] in addition to remodeling as effective management of mechanical symptoms. SSRF techniques were not altered between non-union and acute fractures apart from debridement and graft use.

Graft use

Grafts were generally used if the gap between the ends of non-united ribs was large after exposure and debridement. Autografts were used on all patients by Hernandez et al., Ogunleye et al., and Gauger et al. Hernandez et al. preferred to harvest the autograft from the ipsilateral tibia, whereas Ogunleye et al. and Gauger et al. obtained graft from the iliac crest. [16,19,22] If the gap was larger than a few centimeters, a tricortical structural graft was obtained. If the gap was small, cancellous bone was used. A trephine, micro-oscillating saw, or an osteotome were used to harvest the bone graft. In cases where adjacent ribs had significant malunion, the excess bone was used as an alternative to iliac crest graft [16]. Therefore a multidisciplinary approach including orthopedics teams may be required for managing these patients. Alternatively, synthetic grafts such as NovaBone Putty (manufactured by Novabone Dental) or Tutoplast (manufactured by RTI Surgical), were used by Buehler et al. and de Jong et al. [2,17,23].

Neurectomy or intercostal nerve release

Van Wijck et al. carried out a neurectomy or intercostal nerve release; however, these patients reported significantly less pain reduction than patients who did not have a neurectomy. [18]. Prins and Wijffels also reported a case of neurectomy in which the patient developed flank bulge while continuing to experience severe pain and poor quality of life after the procedure [24].

Outcome measures

Union at follow-up and implant failure

Due to lack of standardized outcomes, we could not provide a pooled rate of non-union after initial operative management. For those that measured non-union at follow-up, confirmation was assessed primarily using chest radiographs performed at variable intervals between 6 weeks and 6 months [16,22,25]. Studies that radiographically confirmed union post-operatively included Gauger et al., Hernandez et al. and DeGenova et al. who reported radiographic union in 47 of 49 (96 %) of patients [16,22,25]. In the Van Wijck et al. study, non-union was not routinely measured, but 2 of the 36 patients (6 %) who required re-operation were found to have non-union at their repeat surgery. [18]

Implant failure is often used as a surrogate for non-union given implant failure is often caused by persistent non-union. Implant failure occurred in 22 of the 229 total patients reported in our studies (11.8 %). The majority of these required re-operation with implant removal and subsequent either rib resection or repeat stabilization. A small number included displaced or “backed-out” screws that were asymptomatic and did not require further operative intervention.

Repeated surgery

Revision surgery was performed for multiple reasons, such as implant failure, infection, persistent pain or irritation, suture granuloma, neuroma formation, or emergence of a new fracture [1,2,11,17–19,22]. The overall rate of re-operation was 13 % (30 of 229 patients). Of these, 18 (10 %) were due to implant failures, persistent non-union, or new peri-implant fractures. Not every case defined as an implant failure required re-operation, for example some screws backing out did not need revision. The rate of revision surgery in each series ranged from 5 % to 33 % among the different cohorts of patients (5,13,16). The time between initial and revision surgery varied from 24 h to 36 months [2,17]. Revision surgery generally resolved the complication and achieved patient satisfaction.

Pain reduction

Four studies (88 patients total) reported the VAS pain scores before and after osteosynthesis, and are presented in Fig. 3[11,17,22,26]. All 4 studies showed a crude reduction in reported VAS scores, with a standardized mean difference (SMD) of -2.81 (CI: -3.57, -2.04, I^2: 68 %). Gauger et al. and Fabricant et al. reported that the majority of patients had improved pain outcomes at final follow-up [1,16]. Ogunleye et al. reported that 53 % of patients had no pain and 29 % had mild pain at final follow-up. [19] Van Wijck et al. reported that 58 % patients had less pain, 33 % similar pain and 8 % had worsened pain at final follow-up. Jong et al. reported that 23 % patients had worsened pain on follow-up, however, the average pain score at 36-months follow-up was 4. [18]

Complications

The overall complication rate in all papers was 27 %. The rate of complications in the case series ranged from 4.5 % to 83 %. A large proportion (10 %) of reported complications were related to implant failure as described previously. Other complications included surgical site infection (4.2 %), seroma/hematoma and other wound problems (5.2 %), pneumothorax or pleural effusion requiring chest tube insertion and neurogenic pain complications (2.2 %). Some case reports also described anatomical injuries, such as a colonic injury due to an unrecognized diaphragmatic hernia [27].

Among the patients in the studies where fixation with plates only was used, 33/97 (38.1 %) experienced complications [1,11,21], whereas among those who underwent both plate fixation and graft use [1,16,19],

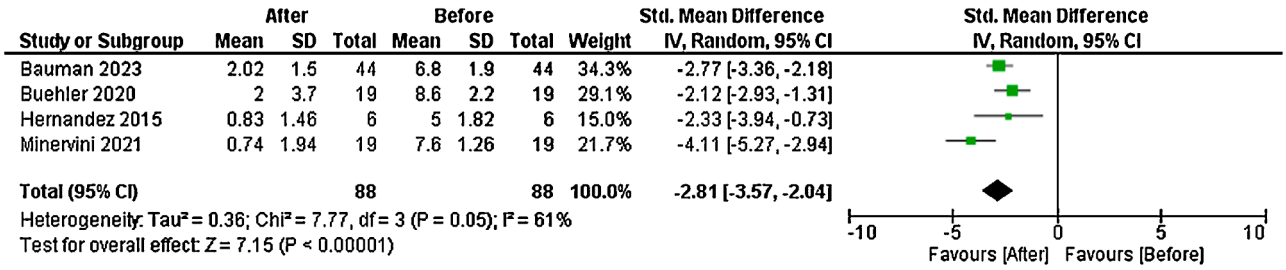

Fig. 3. Pain scores before and after intervention.

a lower rate of complications, 21/79 (26.5 %), was reported. Studies that reported the use of 3D reconstruction modelling (Gauger et al. Hernandez et al. Ogunleye et al. Fabricant et al. de Jong et al.), reported complications in 22/84 patients (26.2 %) whereas, studies that did not use 3D modelling reported complications in 36/136 (26.4 %) patients.

Return to work

Of the four studies that reported return to work status [11,17,18,28] there was an increase in patients ability to work following surgery. The number of patients working pre-operatively was 27 %, which increased to 51 % post-operatively. In the prospective case series by Fabricant et al., there was a possible improvement in chronic pain, but no changes in functional outcomes or work status [1].

Quality of articles

The quality of our included case-series is included in Table 3 and case reports is presented in Table 4. Although case-series studies provide valuable insights into the management of non-union rib fractures, they are generally subject to heterogeneity, selection bias and may limit the generalizability of the findings. Furthermore, all of the included case-series had no comparative population to serve as controls. Similarly, case reports, while offering detailed descriptions of individual cases, have inherent limitations due to their anecdotal nature and small sample sizes.

The quality of the articles in our review varied, and the heterogeneity in study design, the definition of non-union, and surgical techniques further complicated the comparison of results. The results indicated that a majority of the case report and case series met all the basic quality tenets of the CARE checklist, [10] showcasing a rigor in patient selection, exposure and outcome ascertainment, sufficient follow-up and appropriate reporting.

Discussion

In this review, we investigated the diagnosis and management of rib fracture non-union. Our findings revealed that a minimum of 3 months from the initial injury was generally considered necessary for a non-union diagnosis, with 25 % of the case series defining it as >6 months. The median time to surgery was frequently reported between 12 and 24 months, indicating a generally prolonged delay between patients' initial trauma and attempts at definitive management. Although the strength of evidence of the included papers was weak, this is the first scoping review on this topic, and it provides important insights into the diagnosis and management options, as well as outcomes.

Radiographic confirmation of operative success was not done in most studies, but those that did report high union rates. However, a patient-centered outcome such as standardized assessment of symptom relief and/or improvement in quality of life, should be quantified in subsequent studies. Complications were reported in 27 % of the 229 patients across all the articles, with a large proportion related to implant failure. The overall re-operation rate was 13 %. The most common causes for re-operation were implant failure or persistent pain.

Furthermore, among the three studies that reported VAS pain scores before and after osteosynthesis, there was a reduction in reported VAS scores with a standardized mean difference of -2.85, indicating a positive impact on the patient's quality of life. However, no direct measures of quality of life pre- and post- were reported in any study. The number of patients working post-operatively increased following surgical intervention (27 to 51 %), highlighting the importance of understanding and addressing the challenges associated with rib fracture non-unions and their impact on patient function.

Our review demonstrates that surgical management is a viable option for patients with persistent pain and functional impairment. Debridement of callous, fibrous, and atrophic tissue was reported as an

Table 3
A quality assessment of included case-series.

Criterion	Appropriate patient selection with no bias	Exposure Ascertainment	Outcome Ascertainment	Causality- Alternate causes ruled out?	Causality- Sufficient follow-up	Appropriate reporting
Minervini 2021 [11]	Met	Met	Met	Met	Met	Met
Gauger 2015[16]	Met	Met	Met	Met	Met	Met
Hernandez 2015 [22]	Met	Met	Met	Met	Met	Met
Ogunleye 2021 [19]	Met	Met	Met	Met	Met	Met
Fabricant 2013 [1]	Met	Met	Met	Met	Met	Met
Buehler 2020 [17]	Met	Met	Met	Met	Met	Met
De Jong 2018[2]	Met	Met	Met	Met	Met	Met
Van Wijck 2021 [18]	Met	Met	Met	Met	Met	Met
DeGenova 2022 [24]	Met	Met	Met	Met	Met	Met
Bauman 2023 [25]	Met	Met	Met	Met	Met	Met

Table 4
A quality assessment of included case reports.

Criterion	Appropriate patient selection with no bias	Exposure Ascertainment	Outcome Ascertainment	Causality- Alternate causes ruled out?	Causality- Sufficient follow-up	Appropriate reporting
Reber 1993[29]	N/A	Met	Met	N/A	Met	Met
Bergquist 2019[30]	N/A	Met	Met	N/A	Met	Met
Prins and Wijffels 2021[31]	N/A	Met	Met	N/A	Met	Met
Grant and Doben 2019[32]	N/A	Met	Met	N/A	Met	Met
Kaplan 2014[33]	N/A	Met	Met	N/A	Met	Met
Kaplan 2017[34]	N/A	Met	Met	N/A	Met	Met
Sawan 2016[35]	N/A	Met	Met	N/A	Met	Met
Marigi 2020[36]	N/A	Met	Met	N/A	Met	Met
Morgan-Jones 1996 [28]	N/A	Met	Met	N/A	Met	Met
Ng 2001[37]	N/A	Met	Met	N/A	Not met	Met
Slater 2001[38]	N/A	Met	Met	N/A	Met	Met
Cacchione 2000[39]	N/A	Met	Met	N/A	Met	Met
Pedraza 2018[40]	N/A	Met	Met	N/A	Met	Met
Cho 2009[41]	N/A	Met	Met	N/A	Met	Met
Takahara 2004[42]	N/A	Met	Met	N/A	Met	Met
Anavian 2009[43]	N/A	Met	Met	Met	Met	Met
ten Duis 2017[44]	N/A	Met	Met	N/A	Met	Met
Kazakova 2019[20]	N/A	Met	Met	N/A	Met	Met
Van Wijck 2023[21]	N/A	Met	Met	N/A	Met	Met

important step while protecting the intercostal neurovascular bundle. Grafts were used when necessary, followed by osteosynthesis using diverse plating systems. While there is no consensus on the best surgical approach, our findings suggest that centers using 3D reconstruction modeling and incorporating both plate fixation and the use of grafts may have better outcomes with lower complication rates.

There are important limitations in our review. The included studies are predominantly case series and case reports, which may introduce selection bias and limit the generalizability of the findings. Furthermore, the findings in this review are likely subject to reporting and publication bias, as surgeons who have experienced unfavorable outcomes with rib fracture non-union may not have published their studies. Lastly, the studies used various definitions of non-union, ranging from a minimum of 2 months to over 6 months from the initial injury, which could impact the comparability of the results.

There are currently several gaps in our knowledge in the management of rib fractures non-union. Firstly, there is no consensus on the threshold of gap size that necessitates bone grafting for rib fractures non-union. Some studies suggest that gaps larger than 2 mm may benefit from bone grafting, while others report successful outcomes without bone grafting regardless of gap size. [18,26] There is also limited evidence on the comparative effectiveness of different types of bone grafts for rib fractures non-union, such as autograft, allograft, xenograft, or synthetic graft.

Additionally, the impact of risk factors on the outcome of rib fractures non-union is not well quantified or validated. Some possible factors include smoking, infection, osteoporosis, diabetes, obesity, and poor compliance with postoperative care. Lastly, as our studies show, there is no clear definition of when a rib fracture becomes a non-union, and when the surgical intervention should be performed.

Conclusion

Common symptoms of rib fracture non-union include chest pain, clicking, dyspnea and chest deformity. Surgical repair of rib fracture non-union has been shown in several case reports and series as effective treatment with acceptable implant failure and complication rates. Surgical management should therefore be considered as a viable option for symptomatic patients. Further research is required to determine optimal management strategies that further reduce surgical complications for these patients.

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CRediT authorship contribution statement

Robert Chris Adams-McGavin: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Asad Naveed:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Teruko Kishibe:** Methodology, Investigation. **Andrew Beckett:** Writing – review & editing, Supervision. **Aaron Nauth:** Writing – review & editing, Methodology. **Jeremy Hsu:** Writing – review & editing. **David Gomez:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2024.111553.

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