



Published in final edited form as:

J Trauma Acute Care Surg. 2025 February 01; 98(2): 277–286. doi:10.1097/TA.0000000000004517.

Chest Wall Injury Society recommendations for long-term follow-up after nonoperatively and operatively managed traumatic rib and sternal fractures

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Abstract

Rib and sternal fractures are commonly encountered with 10% to 20% of injured patients presenting to the emergency department (ED) with this pathology.^{1,2} These injuries exist along a spectrum, from single, nondisplaced rib fractures to clinical flail chest with paradoxical chest wall motion.³ Similarly, treatment for rib and sternal fractures ranges from oral and intravenous pain medication, to locoregional analgesia, to cryoneurolysis of intercostal nerves, to surgical

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AUTHORSHIP

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This study was presented at the annual meeting of the Chest Wall Injury Society, April 13, 2024, in Salt Lake City, Utah.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

DISCLOSURE

Conflicts of Interest: Author Disclosure forms have been supplied and are provided as Supplemental Digital Content (<http://links.lww.com/TA/E137>).

stabilization of rib fractures (SSRF) and surgical stabilization of sternal fractures (SSSF).² In-hospital complications associated with these fractures include development of pneumonia, hemothoraces, pneumothoraces, and need for mechanical ventilatory support, among others.⁴ For patients undergoing SSRF and SSSF, in-hospital complications can additionally include surgical site infections (SSIs), implant failure, and postsurgical bleeding.^{5,6} While in-hospital complications associated with rib fractures and their treatment are well-documented, timing and frequency of long-term outpatient complications associated with rib fractures or their treatment are less well-described. Consequently, little standardization of outpatient follow-up exists for patients with rib and sternal fractures who undergo nonsurgical and surgical management. The Chest Wall Injury Society (CWIS)'s Publication Committee convened to develop pragmatic recommendations to guide duration of follow-up for patients with nonoperative and operative treatment of rib and sternal fractures.

Keywords

Injury; trauma; nonunion; hemothorax; pain; pneumonia

OBJECTIVES

Clinical Question 1: In adult patients with traumatic rib or sternal fractures undergoing nonoperative management, what is the optimal duration and frequency of follow-up to identify modifiable, postdischarge sequelae of injury?

Clinical Question 2: In adult patients with traumatic rib or sternal fractures undergoing SSRF or SSSF, what is the optimal duration and frequency of follow-up to identify modifiable postsurgical, postdischarge complications?

PATIENTS AND METHODS

Methodology for this practice management guideline was based on the framework described by Arksey and O'Malley⁷ and conforms to multidisciplinary international Reporting Items for Practice Guidelines in Healthcare Working Group standards⁸ (Supplemental Digital Content, Supplementary Data 1, <http://links.lww.com/TA/E135>). A guidelines team with experience in trauma and chest wall surgery, epidemiology, and systematic reviews was established to determine the clinical question and study protocol. A member of the lay public was included to provide patient perspective. Review consisted of five phases: establishment of clinical question and outcomes, identification of relevant studies, study selection, data abstraction, and collation and summary of results.⁹

On September 9, 2023, a research librarian designed and performed searches of four bibliographic databases: PubMed, Embase, Web of Science, and Cochrane (Supplemental Digital Content, Supplementary Data 2, <http://links.lww.com/TA/E136>). Only English language manuscripts or manuscripts that could be translated into English were reviewed. Studies published in year 2003 or later were included to maximize capture of relevant studies. Systematic reviews, commentaries, operative technique descriptions, active clinical trials, and animal studies were excluded. Studies with a majority ($\geq 50\%$) of pediatric

patients in their study population were excluded. Subgroup analysis was performed for patients treated nonoperatively and operatively.

Database results were uploaded into Covidence, a Cochrane-sanctioned, Web-based application. Upon completion of the electronic literature search, titles and abstracts from citation lists were reviewed by six authors to identify potentially relevant studies. Any disagreement about study inclusion was resolved by consensus with a third reviewer. Full-text review and data abstraction were performed by six authors.

For qualitative synthesis, we set no minimum number of patients per study. Quality and certainty of published evidence were evaluated using Grading of Recommendations, Assessment, Development, and Evaluations definitions. Risk of bias was assessed with the Risk of Bias in Nonrandomized Studies of Interventions I tool.¹⁰ Pediatric patients were defined as patients younger than 18 years. Modifiable postdischarge sequelae of injury or surgery had to be recorded with a time frame specified since discharge, injury, or surgery. For nonoperatively treated patients, potentially modifiable postdischarge sequelae of injury were defined as symptoms, which, once detected, resulted in therapeutic intervention or consult to a specialist, readmission, pneumonia, delayed hemothorax requiring intervention, surgery for nonunion, postdischarge nerve block, or postdischarge referral to pain management. A modifiable postdischarge, postsurgical complication was defined as implant or SSI, implant failure or implant pain requiring implant removal, nonunion requiring reintervention, postsurgical nerve block, or consult to a pain medicine specialist after discharge. Missing data were sought from corresponding authors. Degree of bias and certainty was reported after group consensus. Using iterative consensus, all committee members voted to accept or reject recommendations. The intended primary guideline users include trauma surgeons, orthopedic surgeons, thoracic surgeons, primary care providers, ED physicians, patients, and pain management specialists. The setting for which the guideline is intended includes outpatient and inpatient settings.

This study was institutional review board exempt because all articles were publicly available.

RESULTS

Clinical Question 1

Qualitative Synthesis: In total, 2,155 studies were identified, with 7 studies used to inform responses to the clinical question (Fig. 1). No prior existing systematic or scoping reviews were identified. Included studies were published between 2012 and 2022. Among seven included studies, all were cohort studies with three prospective and four retrospective. Four were multi-institution studies. In total, 121,615 patients underwent nonoperative management for their rib fractures with 847 patients (0.7%) experiencing potentially modifiable postdischarge sequelae of injury. Among these patients, 830 complications (98%) occurred within 30 days (Fig. 2). Each study is described hereinafter (Table 1).

In 2012, Chauny et al.¹¹ published a prospective multicenter cohort study evaluating 1,057 patients with minor rib or sternal injury discharged from the ED. Patients were

followed for 4 to 12 weeks after discharge to assess for development of pneumonia.¹¹ The authors identified pneumonia development a median of 11 days (range, 2–14 days) postdischarge.¹¹ Similarly, in 2015, Émond et al.¹² published a prospective multicenter cohort study evaluating 482 patients discharged from an ED. Patients underwent 30-day and 90-day follow-up. Fifty-nine patients (12%) experienced delayed hemothorax ≤ 14 days of ED discharge. No measure of central tendency was provided.¹² In 2016, Racine et al.¹³ published a multicenter prospective cohort study of 969 patients discharged from the ED with isolated sternal fractures with 30-day and 90-day follow-up. In this cohort, 12 patients (1%) developed delayed hemothoraces within 14 days.¹³ No measure of central tendency was provided.¹³ All three studies exclusively evaluated Canadian populations.^{11–13}

In 2018, Dehghan et al.¹⁴ published a multicenter, retrospective cohort study evaluating patients 16 years or older admitted with chest wall injury from 2004 to 2015, comparing those treated with SSRF with those who did not. In the nonoperative cohort of 117,127 patients, 614 (0.5%) developed pneumonia within 30 days of hospitalization. No measure of central tendency was provided.¹⁴ Baker et al.¹⁵ in 2019 published a retrospective, single-institution cohort study evaluating 1,717 patients with moderate to severe chest wall injury treated nonoperatively, evaluating for unplanned readmission after hospital discharge. The authors found 125 patients (7%) readmitted or reevaluated in the ED between 0 and 30 days postdischarge for chest wall specific issues and 17 patients (1%) readmitted or reevaluated in the ED between 31 and 90 days postdischarge.¹⁵ No other measure of central tendency or distribution was provided.¹⁵ In 2021, Choi et al.¹⁶ published a retrospective, single-institution cohort study of 14 adults 50 years or older diagnosed with delayed hemothorax after rib fractures between March 2018 and September 2019. The authors found 8 patients (57%) readmitted for a delayed hemothorax an average of 9 days (range, 2–20 days) after discharge.¹⁶ Finally, in 2022, Deluca et al.¹⁷ published a retrospective, single-institution cohort study describing 249 adults with 2 or fewer rib fractures. In this cohort, six patients (2%) developed rib-specific complications (one hemothorax and five pneumothoraces) requiring tube thoracostomy, all within 1 week of discharge.¹⁷ No measure of central tendency was provided.¹⁷

Recommendation: We considered available evidence describing follow-up after nonsurgical management of rib fractures describing timing of potentially modifiable, postdischarge complications. Overall quality of the body of evidence was rated as low. Risk of bias was moderate for four studies, serious for two studies, and critical for one study. Publication bias was assumed. All studies evaluated North American populations. Long-term follow-up data were rarely presented. No reviewed studies described risk of nonunion, need for postdischarge pain blocks, or need for referral for ongoing pain medicine care. Presence of risk of bias assessment as serious or critical for several studies lowers the quality rating of our recommendation. Despite limitations, lower quality evidence suggests that most potentially modifiable, postdischarge complications after nonsurgical management of rib fractures tend to occur within the first month after discharge. Indirectness of the primary outcome measure lowers the quality rating. We conditionally recommend that patients with nonoperatively managed rib fractures are offered follow-up for at least a month after their injury to evaluate for possible complications. Future studies evaluating patients

undergoing nonsurgical management of rib fractures are encouraged to include information on development of nonunion, outpatient pain medicine referrals, and need for additional locoregional anesthesia postdischarge.

(Grade 2C)

Clinical Question 2

Qualitative Synthesis: In total, 2,155 studies were identified, with 21 studies used to inform the responses to the clinical question (Fig. 1). No prior existing systematic or scoping reviews were identified. Included studies were published from 2003 to 2023. Among the 21 studies, 15 were cohort studies (2 prospective and 13 retrospective), 3 were case-control studies, 2 were case series, and 1 was a randomized controlled trial. In total, 2,881 patients undergoing SSRF or SSSF were described with 94 patients (3%) experiencing a potentially modifiable postsurgery, postdischarge sequelae. Seventy-eight complications (83%) occurred within 1 year, and 16 (17%) occurred after 1 year. In patients who had complications within 1 year, only 27 (35%) experienced their complication at 1 month, which increased to only 37 (47%) by 2 months (Fig. 3). Each study is described hereinafter (Table 2).

In 2003, Mayberry et al.¹⁸ described a single-institution case series of 10 patients undergoing SSRF (1 patient underwent both SSRF and SSSF) with absorbable plates. Ten weeks postoperatively, one patient (10%) developed a *Staphylococcus aureus* SSI, which cleared with wound packings and serial wound packings.¹⁸ This was followed by Ciriaco et al.¹⁹ in 2009 who reported a single-institution case series describing six patients undergoing SSSF, one (15%) who underwent implant removal at 3 years because of persistent pain. In 2013, Bottlang et al.²⁰ published a prospective, multicenter cohort study of 19 patients undergoing SSRF (1 of whom had SSSF as well). One patient (5%) developed an SSI 30 days after their index operation at which point the implants were removed.²⁰ In 2014, Said et al.²¹ published a retrospective, single-institution cohort study of 20 patients with flail chest undergoing SSRF. In this group, one patient (5%) required reoperation at 1 year from their index operation for “additional fixation of a single rib fracture”; implant failure or presence of nonunion was not specified.²¹ These studies were followed by Caragounis et al.,²² who, in 2016, published a prospective, single-institution cohort study of 49 patients undergoing SSRF for multiple rib fractures and flail chest. One patient (2%) developed osteomyelitis and by 7 months underwent reoperation and implant removal for implant-related infection.²²

Also, in 2016, Thiels et al.²³ published a retrospective, single-institution cohort study of 122 patients undergoing SSRF, 58 (48%) of whom had flail chest. Five developed SSI or implant-related infection (median, 12 days; interquartile range, 7–18 days) postoperatively.²³ In 2017, Kocher et al.²⁴ published a retrospective, single-institution cohort study of 61 patients who underwent SSRF (9 also underwent concomitant SSSF). One patient in this cohort developed a superficial SSI, although no time to development of this complication was presented.²⁴ One patient (2%) did have their sternal implant removed 2 years after the index operation because of ongoing pain.²⁴ In 2018, Liu et al.²⁵ published a single-institution case-control study of 110 patients with multiple rib fractures. Of the 59 patients in the intervention arm, one patient (2%) underwent implant removal 12 months after the index operation because of chronic pain.²⁵

In 2018, Dehghan et al.¹⁴ published a retrospective, multicenter cohort study evaluating patients admitted with chest wall injury. Of 117,204 patients, 77 (0.07%) underwent SSRF.¹⁴ Of those undergoing surgery, 10 (13%) developed an SSI or implant-related infection within 30 days of the index operation (no measure of central tendency reported), and one patient (1%) had an implant complication within 1 year of the index surgical intervention.¹⁴ Also in 2018, Drahos et al.²⁶ published a retrospective, single-institution cohort study describing 156 patients undergoing SSRF, of whom one patient (1%) developed an SSI or implant-related infection 6 months to 1 year after the index operation and one patient developed an SSI or implant-related infection ≥ 2 years after the index operation.

In 2019, Beks et al.²⁷ published a retrospective, single-institution cohort study describing 166 patients who underwent SSRF. Among 66 patients who underwent SSRF for flail chest, five patients (3% of total) had implants removed (mean, 1.1 years; range, 0.6–1.6 years) postoperatively, while, among 100 patients with multiple rib fractures undergoing SSRF, 4 (2% of total) underwent implant removal (average, 1.8 years; range, 0.9–4.2 years) postoperatively.²⁷ All of these patients had implants removed for implant related irritation.²⁷ Finally, in 2019, Sarani et al.⁵ published a retrospective, multicenter cohort study describing 1,224 patients who underwent SSRF. Among these patients 26 patients (2%) were reported to have implant failure requiring removal at a median of 89 days (range, 12–164 days) postoperatively, with “infection...the presenting sign of hardware failure in 8% of cases.”⁵

In 2020, Lodin et al.²⁸ published a retrospective, single-institution cohort study evaluating 71 patients undergoing surgery for rib fractures; 49 patients underwent SSRF, 12 underwent SSSF, and 10 underwent both SSRF and SSSF. Two patients (3%) developed an SSI or implant-related infection at 4 weeks and 32 weeks, respectively.²⁸ Also, in 2020, Wijffels et al.²⁹ published a single-institution case-control study comparing 47 nonoperatively treated patients to 23 patients who underwent SSRF for flail chest. Three patients (13%) developed an SSI or implant-related infection (median, 26 days; range, 20–26 days) postoperatively.²⁹ Gargur Assuncao et al.³⁰ published a multicenter, retrospective cohort study in 2021 evaluating 144 patients who underwent repair of one or more subscapular rib fractures. In this cohort, three patients (2%) developed SSI or implant-related infections (median, 219; range, 42–419 days) postoperatively; two patients (1%) had implants removed because of implant pain or failure at 177 and 359 days postoperatively, respectively.³⁰

Also, in 2021, Schuette et al.³¹ published a retrospective, single-institution cohort study of 26 patient who underwent SSRF, in whom one patient (4%) developed an SSI or implant-related infection 3 years postoperatively. Infection was associated with attempted intravenous self-injection of heroin.³¹ By 2022, Dehghan et al.³² published a prospective, randomized multicenter trial comparing patients with rib fractures undergoing SSRF with those receiving nonoperative therapy. In the 111 patients who underwent SSRF, one (1%) had a rib-specific readmission at 12 days, nine (8%) developed SSI or implant-related infections 2 to 40 days postoperatively (no measure of central tendency provided), and one patient (1%) had their implant removed for implant failure or implant associated pain at 6 months postoperatively.³² Niziolek et al.,³³ in 2022, published a multicenter case-control study comparing 45 patients undergoing SSRF with 36 patients who underwent nonoperative

therapy. In this study, one patient (2%) underwent implant removal at 9 months because of implant-related pain.³³

In 2022, Prins et al.³⁴ published a retrospective, single-institution cohort study evaluating 228 patients who underwent SSRF (4 underwent both SSRF and SSSF) to evaluate for predictors of SSI or implant-related infection. Of the four patients (2%) who experienced an SSI or implant-related infection, these were identified at a median of 98 days (range, 6–210 days) postoperatively.³⁴ Also, in 2022, van Gool et al.³⁵ published a retrospective, single-institution cohort study evaluating 105 patients undergoing video-assisted thoracoscopic SSRF. In this cohort, one patient (1%) had a rib-specific readmission at 16 days, one patient (1%) had an SSI or implant-related infection detected at 28 days postoperatively, and one (1%) had an implant failure detected 40 days postoperatively.³⁵ Finally, in 2022, Belaroussi et al.³⁶ published a retrospective, single-institution cohort study of 159 patients who underwent SSRF for multiple rib fractures or flail chest. In this cohort, one patient developed an SSI or implant-related infection “within the first month.”³⁶

Recommendation: We considered available evidence describing follow-up after SSRF or SSSF describing timing of potentially modifiable postdischarge, postsurgical complications. Overall quality of the body of evidence was rated as low. Risk of bias was low for 1 study, moderate for 5 studies, serious for 12 studies, and critical for 3 studies. Publication bias was assumed. Presence of risk of bias assessment as serious or critical for several studies lowers the overall quality rating. All studies were performed in North American or European populations. No reviewed studies described risk of nonunion, need for postdischarge pain blocks, or need for referral for ongoing pain medicine care limiting ability to provide recommendations for these outcomes. Lower quality evidence suggests most potentially modifiable, postdischarge complications after SSRF and SSSF tend to occur within the first year after discharge, with a majority occurring within 3 months. Indirectness of the primary outcome measure lowers the quality rating. We conditionally recommend patients undergoing SSRF or SSSF have planned follow-up visits for at least 3 months after surgery, with additional follow-up scheduled as needed based on symptoms. Future studies evaluation patients undergoing SSRF or SSSF are encouraged to include information on development of nonunion, outpatient pain medicine referrals, and need for additional locoregional anesthesia postdischarge.

(Grade 2C)

DISCUSSION

Using This Guideline in Clinical Practice

Follow-up after injury or surgery is a complex interaction between physician or surgeon expectations, patient compliance and desire, accessibility, medicolegal concerns, health care reimbursement, and compensation, superimposed upon the natural history of a given injury or surgical intervention.³⁷ While emphasis has been placed on in-hospital outcomes among patient with rib fractures, understanding outcomes occurring after discharge is essential, particularly because these outcomes may be as, if not more, impactful to a patient.^{37–39} Nonetheless, our ability to understand long-term outcomes after nonsurgical or surgically

managed rib or sternal fractures is limited without standardized follow-up duration and frequency.

Historically, reporting outcomes out to 30 days postoperatively were considered best practice.³⁸ However, in the cases reviewed for this guideline, only 29% of all postdischarge, postsurgical outcomes would have been captured using a 30-day threshold, suggesting an inherent publication bias. This publication bias may be particularly pronounced among patients who undergo nonoperative therapy. For example, nonunion is not defined until the absence of bony union at 3 months, well outside the range of most follow-up for patients treated nonoperatively.³⁹ Thus, it is not surprising that longer-term outcomes associated with rib fractures (i.e., nonunion, referral to pain medicine services, locoregional blocks) may be underreported. For patients with nonoperatively treated rib fractures, in the absence of scheduled follow-up outside of 30-days, providing opportunity for longer term follow-up may be important if symptoms persist.

Ultimately, there must be a balance between our current understanding of the natural history of recovery after trauma or surgery, time to development of potentially modifiable outcomes or complications, resource constraints on the surgeon and health care system, individual patient recovery trajectories, and financial burden on the patient when establishing recommended follow-up durations. Unfortunately, comprehensive literature bases for each of these variables influencing duration of follow-up do not currently exist. However, based upon published data on time to development of possibly preventable, postdischarge complications, CWIS conditionally recommends: (1) scheduled follow-up for at least 1 month after nonoperatively managed rib or sternal fractures and (2) scheduled follow-up for at least 3 months after SSRF or SSSF. For patients with persistent symptoms or new symptoms outside of these time frames, CWIS encourages referral to a center with expertise in chest wall injury, based on expert consensus.

Limitations

There are several limitations. First, considerable variation exists in patient-reported outcomes limiting direct comparisons between studies. Second, given heterogeneity in reported outcomes, combinatorial analysis of studies was not possible. Third, most studies were retrospective, increasing potential for recall and reporting bias. Publication bias was also present, as no current guideline exists for recommended duration of follow-up. This may be particularly pronounced among the nonoperative patients given reported follow-up durations, which could lead to marked underestimation of long-term complications after nonoperative management. Fourth, cost and resource implications were not included or assessed given anticipated paucity of existing literature. This limited our ability to perform a cost-benefit analysis. Fifth, only North American or European populations were assessed limiting extrapolation to other populations. Sixth, we defined possibly preventable, postdischarge, postinjury, or postsurgical complications, which could limit capture of all possible complications. We also acknowledge that our complications, as defined, were procedurally centered. An alternative strategy for future studies could be to provide recommendations on duration and cadence of follow-up need based on normal healing trajectory, rather than to time to development of complications. Seventh, the intentionality

of follow-up was rarely available in the reviewed manuscripts, so it is not known how many of the complications among patients in either the operative or nonoperative groups were detected as a result of existing planned follow-up or development of symptoms. This indirectness of the primary outcomes assessed lead to lower quality assessments among the reviewed manuscripts. Future studies in these patient populations are encouraged to report duration of intentional follow-up to help delineate this issue. Finally, nearly all studies included in this recommendation guideline had patients lost to follow-up, and it is possible that these patients could have had complications but sought care elsewhere.

CONCLUSION

Lower-level evidence exists to suggest that, for patients with traumatic rib and sternal fractures, scheduled follow-up to at least 1 month for patients managed nonoperatively and for at least 3 months for patients managed operatively would help ensure identification of possibly preventable postdischarge, postinjury, and postsurgery complications. However, the benefit of identification of these possibly preventable complications must be balanced against provider and resource availability and patient preference. For patients with persistent symptoms or new symptoms outside of these time frames, referral to a center or specialist with expertise in chest wall injury is recommended for ongoing management.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGMENT

We thank Chris Stave for his assistance in developing search terms and use of Covidence.

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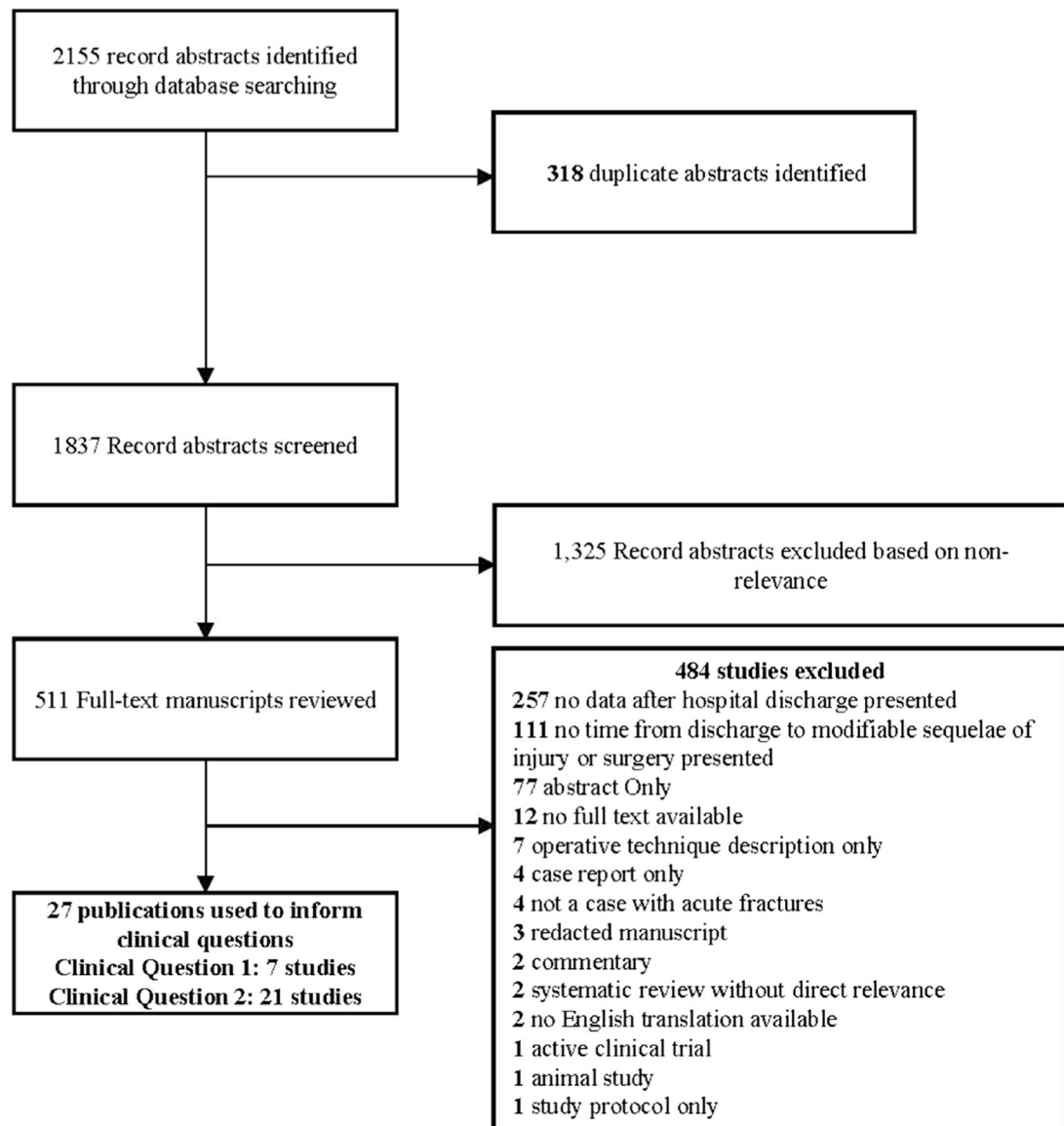


Figure 1.
Flow diagram showing selection process for included manuscripts.

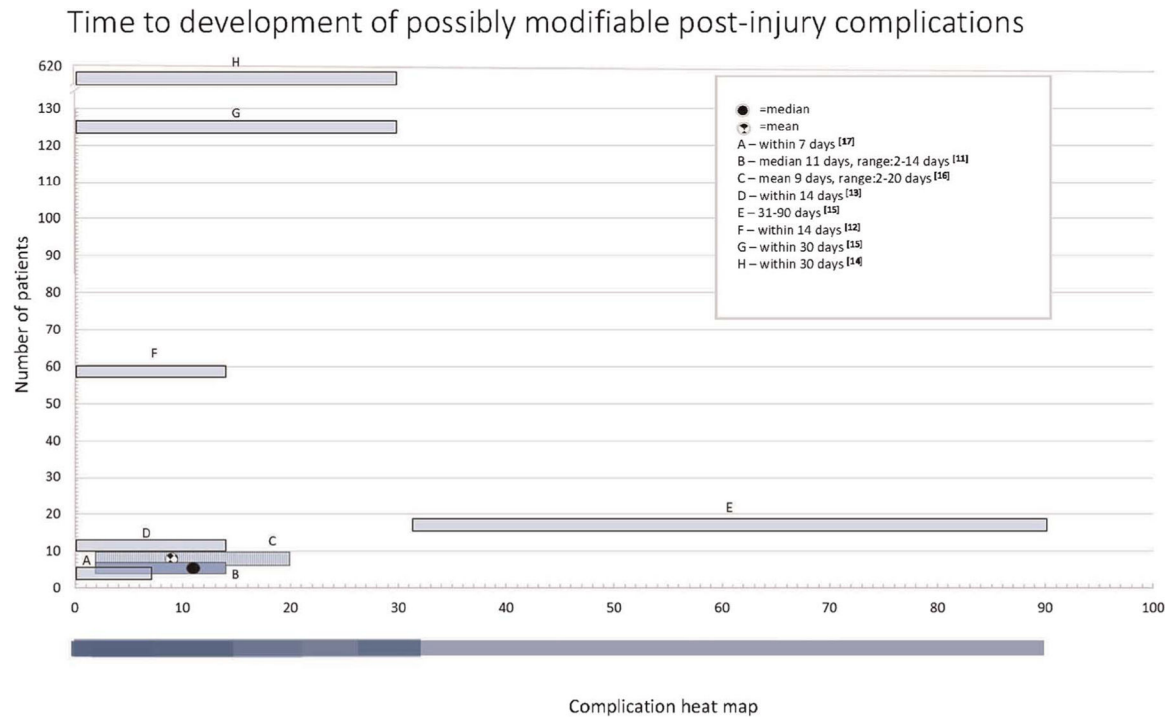


Figure 2.

Time to development of possibly modifiable, postdischarge postinjury complications after nonsurgically treated rib fractures.

Time to development of possibly modifiable post-surgical complications after surgical stabilization of rib or sternal fractures

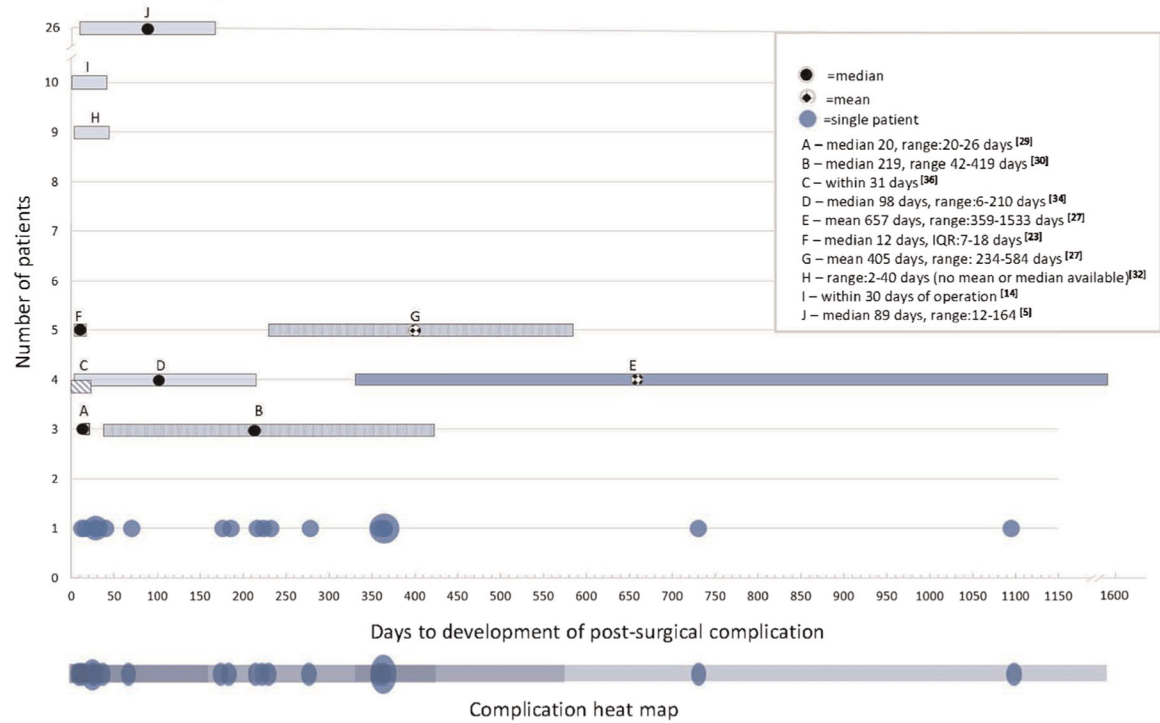


Figure 3.

Time to development of possible modifiable, postdischarge, postsurgical complications after SSRF or SSSF.

TABLE 1.
Articles Identified Through Search Reviewed for Clinical Question 1

Name (Year)	Study Design/Setting	No. Patients Undergoing Nonoperative Therapy	Number and Time to Rib-Specific Readmission	Number and Time to Development of Delayed Hemothorax	Number and Time to Identification of Nonunion or Malunion Requiring Intervention	Number and Time to Placement of Postdischarge Nerve Block	Number and Time to Referral for Pain Medicine Specialist	Other	Risk of Bias
Chauny et al. ¹¹ (2012)	Prospective cohort/multicenter	1,057	6 (Median, 11 d; range, 2–14 d)	0	0	0	0	6 Patients developed pneumonia	Moderate
Émond et al. ¹² (2015)	Prospective cohort/multicenter	482	0	59 (Within 14 d)	0	0	0	—	Moderate
Racine et al. ¹³ (2016)	Prospective cohort/multicenter	969	0	12 (Within 14-d postinjury)	0	0	0	—	Moderate
Dehghan et al. ¹⁴ (2018)	Retrospective cohort/multicenter	117,127	614 (Within 30 d)	0	0	0	0	—	Moderate
Baker et al. ¹⁵ (2019)	Retrospective cohort/single institution	1,717	125 Patients readmitted or reseen in ED between 0 and 30 d, 17 patients readmitted or reseen in between 31 and 90 d	0	0	0	0	—	Serious
Choi et al. ¹⁶ (2021)	Retrospective cohort/single institution	14	0	8 (Mean, 9.3 d; range, 2–20 d)	0	0	0	—	Critical
Deluca et al. ¹⁷ (2022)	Retrospective cohort/single institution	249	6 (Within 1 wk)	0	0	0	0	—	Serious

TABLE 2.

Articles Identified Through Search Reviewed for Clinical Question 2

Name (Year)	Study Design/ Setting	No. Patients Undergoing SSRF or SSSF	Number and Time to Identification of SSI or Implant- Related Infections	Number and Time to Identification of Implant Failure or Implant Pain Requiring Re- intervention	Number and Time to Identification of Nonunion or Malunion Requiring Intervention	Number and Time to Placement of Postdischarge Nerve Block	Number and Time to Referral for Pain Medicine Specialist	Comments	Risk of Bias
Mayberry et al. ¹⁸ (2003)	Case series/ single center	10 Total (1 combined SSSF and SSRF)	1 (10 wk)	0	0	0	0	—	Critical
Ciriaco et al. ¹⁹ (2009)	Case series/ single center	6 SSSF	0	1 (3 y)	0	0	0	Plate removed for persistent pain, no underlying pathology	Critical
Botlang et al. ²⁰ (2013)	Prospective cohort/ multicenter	19 SSRF	1 (30 d)	0	0	0	0	—	Moderate
Said et al. ²¹ (2014)	Retrospective cohort/single institution	20 SSRF	0	1 (12 mo)	0	0	0	—	Serious
Caragounis et al. ²² (2016)	Prospective cohort/single institution	49 SSRF	1 (7 mo)	0	0	0	0	—	Serious
Thiels et al. ²³ (2016)	Retrospective cohort/single institution	122 SSRF	5 (Median, 12 d; IQR, 7–18 d)	0	0	0	0	—	Serious
Kocher et al. ²⁴ (2017)	Retrospective cohort/single institution	61 SSRF (9 also had SSSF)	0	1 (2 y)	0	0	0	Stemal plate removed for persistent pain, no underlying pathology	Serious
Liu et al. ²⁵ (2018)	Case control/ single institution	59 SSRF	0	1 (12 mo)	0	0	0	Plate removed for persistent pain, no underlying pathology	Serious
Dehghan et al. ¹⁴ (2018)	Retrospective cohort/ multicenter	77 SSRF	10 (Within 30 d of operation)	1 (1 y)	0	0	0	—	Moderate

Name (Year)	Study Design/ Setting	No. Patients Undergoing SSRF or SSSF	Number and Time to Identification of SSI or Implant- Related Infections	Number and Time to Identification of Implant Failure or Implant Pain Requiring Re- Intervention	Number and Time to Identification of Nonunion or Malunion Requiring Intervention	Number and Time to Placement of Postdischarge Nerve Block	Number and Time to Referral for Pain Medicine Specialist	Comments	Risk of Bias
Drahos et al. ²⁶ (2018)	Retrospective cohort study/ single institution	156 SSRF	0	2 (Median, 15.75 y; range, 7.5 mo to 2 y)	0	0	0	—	Serious
Beks et al. ²⁷ (2019)	Retrospective cohort/single institution	166 SSRF	0	0	Among 66 pts with flail chest, 5 patients (13%) had their implant removed (on average, 1.1 y; range, 0.64–1.6 y) postop Among pts with multiple rib fractures, 4 patients underwent removal (on average, 1.8 y; range, 0.9–4.2 y) postop	0	0	For plate irritation, no underlying pathology identified	Serious
Sarani et al. ⁵ (2019)	Retrospective cohort/ multicenter	1,224 SSRF	0	26 (Median, 89 d; range, 12–164 d)	0	0	0	“Infection was the presenting sign of hardware in 8% of cases”	Moderate
Lodin et al. ²⁸ (2020)	Retrospective cohort/single institution	71 Total (49 SSRF, 12 SSSF, 10 both SSRF and SSSF)	0	2 (Median, 20 wk; range, 4–32 wk)	0	0	0	—	Serious
Wijffels et al. ²⁹ (2020)	Case control/ single institution	23 SSRF	0	3 (Median, 26 d; range, 20–26 d)	0	0	0	—	Critical
Gargur Assuncao et al. ³⁰ (2021)	Retrospective cohort/ multicenter	144 SSRF	0	3 (Median, 219 d; range, 42–419 d)	2 (Median, 105 d; range, 177–359 d)	0	0	Implant failure was implant “grinding” between scapula and chest wall	Moderate
Schuetz et al. ³¹ (2021)	Retrospective cohort/single institution	26 SSRF	0	1 (3 y)	0	0	0	—	Serious

Name (Year)	Study Design/ Setting	No. Patients Undergoing SSRF or SSRF	Number and Time to Identification of SSI or Implant- Related Infections	Number and Time to Identification of Implant Failure or Implant Pain Requiring Re- Intervention	Number and Time to Identification of Nonunion or Malunion Requiring Intervention	Number and Time to Placement of Postdischarge Nerve Block	Number and Time to Referral for Pain Medicine Specialist	Comments	Risk of Bias
Dehghan et al. ³² (2022)	Prospective randomized trial/ multicenter	111 SSRF	1 (12 d)	9 (Range, 2–40 d)	1 (6 mo)	0	0	—	Low
Niziolek et al. ³³ (2022)	Case control/ multicenter	45 SSRF	0	0	1 (9 mo)	0	0	Plate removed for persistent pain, no underlying pathology	Moderate
Prins et al. ³⁴ (2022)	Retrospective cohort/single institution	228 Total (224 SSRF; 4 both SSRF and SSSF)	0	4 (Median, 98 d; range, 6–210 d)	0	0	0	—	Serious
van Gool et al. ³⁵ (2022)	Retrospective cohort/single institution	105 SSRF	1 (16 d)	1 (28 d)	1 (40 d)	0	0	—	Serious
Belaroussi et al. ³⁶ (2023)	Retrospective cohort/single institution	159 SSRF	0	4 (“Within the first month”)	0	0	0	—	Serious

IQR, interquartile range; postop, postoperative; pts, patients.