



Review

Clinical management of rib fractures and methods for prevention of pulmonary complications: A review



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ABSTRACT

Rib fractures are common injuries associated with significant morbidity and mortality, largely due to pulmonary complications. Despite equivocal effectiveness data, incentive spirometers are widely utilized to reduce pulmonary complications in the postoperative setting. Few studies have evaluated the effectiveness of incentive spirometry after rib fracture. Multiple investigations have demonstrated incentive spirometry to be an important screening tool to identify high-risk rib fracture patients who could benefit from aggressive, multidisciplinary pulmonary complication prevention strategies. This review evaluates the epidemiology of rib fractures, their associated pulmonary complications, along with the evidence for optimizing their clinical management through the use of incentive spirometry, multimodal analgesia, and surgical fixation.

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Background

Rib fractures are the most common type of clinically significant blunt traumatic injury to the thorax [1]. The most common mechanisms of traumatic thoracic injury are motor vehicle crashes, pedestrian versus motor vehicle accidents, falling, and crush injuries [2,3]. Each year, there are an estimated 248,000 emergency department (ED) encounters [4] and 46,000 inpatient

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admissions with a diagnosis of rib fracture in the United States [5]. This may be an underestimate due to the tendency to underdiagnose or underreport rib fractures [6].

The estimated annual incidences of ED encounters and inpatient admissions for rib fractures have increased from 2006 to 2014 (Fig. 1). While the Agency for Healthcare Research and Quality (AHRQ) reports a 7.4% increase in ED visit rates for all causes during this timeframe, the majority of increased utilization stemmed from visits related to mental health or substance abuse [7]. Throughout this same time period, AHRQ estimated a 12.9% decrease in ED visits due to traumatic injury. The rate of ED visits for rib fracture, however, increased by 19.4% (from 65.0 to 77.6 visits per 100,000 persons) [4]. While injury prevention measures may be reducing the overall number of ED visits, this finding suggests that the incidence of rib fractures and blunt chest trauma may be rising, especially among the elderly population at greater risk for falls.

While fall prevention likely remains an important and unmet target for primary prevention of rib fractures among at-risk populations, the clinical management of rib fractures represents an important opportunity for secondary and tertiary prevention measures. This comprehensive review aims to summarize the existing literature on prophylaxis of pulmonary complications following rib fracture, with a specific focus on the role of incentive spirometry. A search of peer-reviewed literature in the English language within MEDLINE-indexed journals was performed and updated in April 2019 using the “Rib Fractures” Medical Subject Heading and a morbidity or mortality identifier (Table 1). Full-length articles presenting the results of interventions to reduce morbidity or mortality following rib fracture, as well as those retrospectively evaluating associations between pulmonary complications and other variables were included. Additionally, cited reference searching and hand searching were used to screen for relevant articles that may have been missed during the initial search. As significant variation exists among reported methodologies and outcomes within the rib fracture literature, thematic analysis and narrative synthesis was performed to provide a broader assessment of the current evidence base compared with systematic review. Additionally, prospective randomized clinical trials identified by this review were tabulated and are included as a supplemental reference (Table 2).

Pulmonary complications associated with rib fracture

The majority of rib fractures heal without significant complications. However, in 2005 an analysis of 64,750 patients with one or more rib fractures entered into the National Trauma Data Bank (NTDB) showed that 13% of these patients experienced one or more complications including pneumonia, ARDS, pulmonary embolus,

pneumothorax, aspiration pneumonia, and empyema [8]. Though the authors acknowledged the confounding effects of concurrent head injury and increased utilization of mechanical ventilation in patients with >6 rib fractures, they observed increasing incidence of pneumonia, ARDS, pneumothorax, aspiration pneumonia, empyema, and mortality with each additional rib fracture [8]. Additional analyses have also demonstrated an increasing incidence of pneumonia with additional rib fractures [8–10].

In addition to increased number of rib fractures, patients aged 65 years or older have been shown to experience significantly higher rates of pneumonia and subsequent mortality in multiple retrospective analyses [9,11]. The overall incidence of pneumonia in patients hospitalized with rib fractures have been reported as 6% across the National (Nationwide) Inpatient Sample (NIS) [12] and ranging from 3 to 8.4% within the NTDB [8], though single-institution studies in tertiary centers have identified higher incidences. The development of pneumonia and other pulmonary complications following rib fracture significantly increases morbidity and mortality. In a recent meta-analysis of patients with blunt chest trauma without other associated injury, patient age greater than 65 years, presence of three or more rib fractures, presence of pre-existing cardiopulmonary disease, and the onset of pneumonia following injury yielded combined odds ratios of 1.98 (1.86–2.11, 95% CI), 2.02 (1.89–2.15, 95% CI), 2.43 (1.03–5.72, 95% CI), and 5.24 (3.51–7.82) for mortality across 29 studies, respectively [13].

In patients presenting with multiple rib fractures, the chest wall stability and respiratory status may be further compromised by the presence of flail chest. Flail chest has been defined as the presence of multiple adjacent ribs fractured in two or more places that creates an unstable segment of the chest wall. The flail segment, which may also include the sternum, exhibits paradoxical motion during spontaneous breathing that may impede the generation of sufficient inspiratory pressures for complete ventilation and gas exchange. Flail chest is also associated with pulmonary contusion and shunt physiology, which further impair oxygenation. Thus, flail chest is the most life-threatening complication of rib fracture in the acute setting, with mortality as high as 33% in retrospective analyses [14]. Patients with flail chest often require ICU admission, and a majority require respiratory support via mechanical ventilation [15]. Recent studies and meta-analyses examining the role of surgical fixation for flail chest have also observed rates of pneumonia as high as 35 and 80% in patients with operative and non-operative management, respectively [16,17].

While rib fractures may lead to other complications including fracture non-union, intercostal nerve entrapment, and chronic pain and disability, the prevention and treatment of pulmonary complications in the acute phase, including pneumonia and atelectasis, remains an essential component of clinical management.

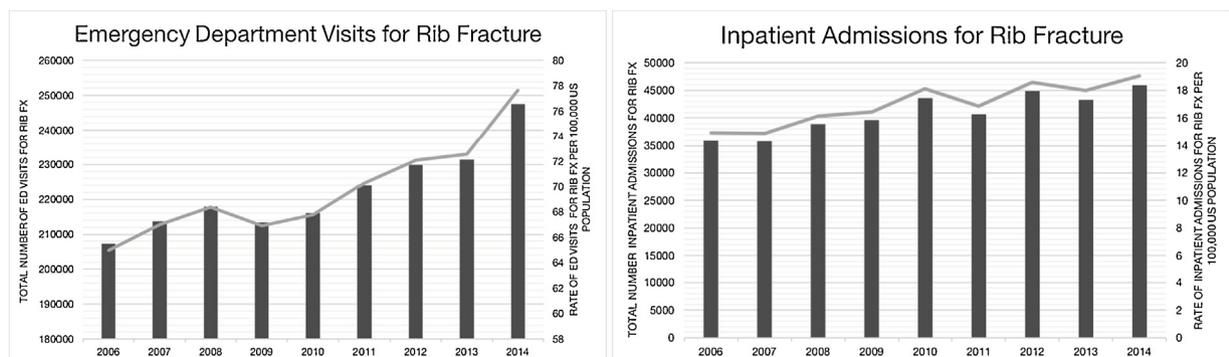


Fig. 1. Annual Incidence of Rib Fracture in the United States.

Table 1
Search Terms and Strategies.

Rib Fractures	Pulmonary Complication Identifier	
"Rib Fractures" [MeSH]	mortality[tiab], morbidity[tiab], complication[tiab], pulmonary complication [tiab], length of stay[tiab]	pneumonia[tiab], ARDS[tiab], pulmonary embolism [tiab], pneumothorax[tiab] empyema[tiab]

Guidelines for clinical management

The majority of rib fractures are not life threatening and are treated nonoperatively; however, thorough and careful protocolized care is needed to optimize patient outcomes and reduce morbidity and mortality. Current standards for conservative treatment focus on providing adequate pain management and promoting pulmonary hygiene. The goals of pain management in these patients are both to increase overall comfort as well as to decrease intercostal muscle contraction and spasm around the fracture sites through provision of local analgesia. Concurrently, pain management should also aim to avoid the deleterious effects of opioids on minute ventilation and the maintenance of airway patency. Achievement of both goals is associated with the ability to take deeper breaths and avoid excessive splinting and atelectasis, as measured by improvements in oxygenation and peak expiratory flow rate and clearance of respiratory secretions [18]. Should patients require advanced respiratory support, three recent systematic reviews support the use of NIPPV among patients with chest trauma who present without indications for emergent intubation [19–21]. Alternative oxygenation strategies including high-flow nasal cannula remain to be evaluated among patients with rib fractures or blunt chest trauma.

The use of multimodal analgesia in patients with rib fractures has received increasing attention in recent years. Retrospective cohort studies from single institutions have demonstrated that early administration of parenteral NSAIDs to patients with rib fractures may decrease opioid requirements, length of stay [22], pneumonia incidence, number of ventilator days, and ICU length of stay [23]. A multicenter analysis of patients with rib fractures across eight regional trauma centers found that patient-controlled analgesia may be a significant predictor of decreased mortality, though parenteral NSAIDs did not offer mortality reduction [24]. A randomized, controlled, double-blinded trial of three times daily 300 mg gabapentin versus placebo for 30 days following at least one rib fracture was recently completed for patients aged less than 65 years admitted to a single trauma service. Despite similar baseline characteristics, including amounts of acetaminophen and ibuprofen administered and the presence of regional anesthesia, the authors found no statistical difference in numerical pain scores, opioid requirements, incentive spirometry volumes, respiratory rate, or oxygen requirement during the index admission, or in one-month quality of life scores between groups [25]. Recently, a prospective, randomized, double-blind placebo-controlled trial of low-dose ketamine in adults with three or more rib fractures demonstrated that among patients with an ISS > 15, a ketamine infusion at 2.5 ug/kg/min for 48 h was associated with a significant decrease in oral morphine equivalent utilization compared with controls [26]. However, the authors were unable to demonstrate any statistically significant difference in utilization among all patients, as well as length of stay and rates of pulmonary complications or adverse events [26].

A recent meta-analysis of 19 studies comparing the efficacy of interventions including epidural analgesia, intravenous analgesia, and intercostal and paravertebral blocks found that administration

of epidural analgesia to patients with multiple rib fractures results in significant pain reduction compared with the other modalities [27]. This meta-analysis demonstrated no difference in secondary outcomes such as rates of complication, length of mechanical ventilation, or length of stay in ICU, though previous retrospective analyses of epidural analgesia following rib fracture have identified reductions in those same outcomes. While one large analysis reported decreased mortality and unchanged rates of pneumonia with epidural analgesia, the authors acknowledged that this may be the result of low utilization (2.2%) and selection bias [8]. Smaller analyses of thoracic epidural and paravertebral catheter analgesia have yielded similarly ambiguous results [28,29]. A recent matched analysis of 1360 patients presenting to a trauma center with at least one rib reported that epidural analgesia was not associated with a mortality benefit and was actually associated with significantly higher rates of respiratory complications, defined as pneumonia, respiratory failure, and pulmonary embolism or deep vein thrombosis in patients without penetrating mechanisms or traumatic brain injury who did not receive laparotomy or thoracotomy [30]. Though there was no research identified evaluating the effectiveness of serratus anterior plane blocks (SABP) following rib fracture, a randomized controlled trial of preoperative ultrasound-guided SABP prior to thoracoscopic surgery decreased intraoperative remifentanyl and 24-hour fentanyl requirements compared to placebo [31]. Additionally, a randomized, comparative, observer-blinded study of postoperative SABP with catheter placement prior to extubation after thoracotomy found no significant difference in pain scores or morphine requirements as compared to thoracic epidural analgesia [32]. Future studies may consider evaluating the efficacy of SABP following multiple rib fractures.

For patients who fail to respond to conservative management, surgical management, including open reduction and internal fixation (ORIF) of affected ribs, may be indicated. Though no published guidelines exist regarding patients without flail chest, a recent literature review supports early surgical stabilization within 72 h in patients with three or more displaced rib fractures, flail segment including sternal flail or fractures, and those requiring video-assisted thoracoscopic surgery or thoracotomy for other indications [33]. In select patients with flail segments, ORIF has been associated with significant reductions in need for tracheostomy tube placement, mechanical ventilation time, incidence of pneumonia, long-term pain, and mortality compared to conservative management alone [34–43]. Accordingly, the Eastern Association for the Surgery of Trauma published guidelines recommending operative fixation for patients with flail chest in 2017 [44]. However, recent evidence suggests that although ORIF may be beneficial during a patient's index admission, there may be limited difference in quality of life or pain benefit 24 months following injury [45]. The advent of newer techniques including minimally invasive internal fixation during video-assisted thoracoscopic surgery [46] may allow for faster and improved recovery compared with ORIF, however, further research is needed.

Despite these findings, patients older than 65 years or with pre-existing cardiopulmonary disease may not be identified as acceptable-risk candidates for rib fracture plating, further contributing to the elevated morbidity and mortality in these populations. Some surgeons' lack of familiarity with thoracic ORIF may also reduce its implementation in appropriate circumstances. In a survey of 238 trauma surgeons, orthopedic trauma surgeons, and thoracic surgeons, only 26% reported that they had performed or assisted with a chest wall fracture repair [47]. Without ORIF, primary fracture nonunion and its sequelae may occur. Fabricant et al [48] found that 38% of patients with rib fracture nonunion experience intercostal nerve entrapment, a significant contributor to chronic pain and disability. This study also found that chronic

Table 2
Evidence from Randomized Controlled Trials to Decrease Pulmonary Complications after Rib Fractures.

Authors (date)	Study Design (N)	Population	Intervention(s) and Comparator(s)	Outcomes	Key Findings
<i>Non-operative Management</i>					
Moskowitz et al. (2018)	Randomized, double-blind, placebo-controlled trial (N = 40)	Adult patients <65 years old with 1 or more rib fractures requiring hospital admission Exclusions: intubation, pregnancy, traumatic brain injury, renal or hepatic impairment, gabapentin hypersensitivity, inability to tolerate oral medications or obtain consent	300 mg gabapentin tid for one month post-injury Placebo* *All patients received usual care including NSAIDs, opiates, and/or locoregional anesthesia during their admission	Primary: daily average numeric pain score Secondary: opioid requirement, oxygen requirement, respiratory rate, best IS volume recording, ICU and overall length of stay, overall and chest-specific quality of life, mechanical ventilation, pneumonia, mortality	No observed differences between groups in the primary or secondary outcomes. Of note, there were no incidences of pneumonia, respiratory failure, or mortality in either group.
Carver et al. (2019)	Randomized, double-blind, placebo-controlled trial (N = 91)	Adult patients <65 years old with 3 or more rib fractures Exclusions: GCS < 14, active acute coronary syndrome, active delirium or dementia, pregnancy or prisoner status, prolonged sBP > 180 mm Hg or dBP > 100 mm Hg, current substance abuse (opiate or ketamine), current use of monamine oxidase inhibitors use or 3 or more other psychotropic medications, history of glaucoma, chronic opiate use, psychosis or adverse reactions to ketamine	Low-dose ketamine infusion (2.5 µg kg ⁻¹ · min ⁻¹) within 12 h admission for a duration of 48 h Placebo* *All patients received usual care including NSAIDs, opiates, and/or locoregional anesthesia during their admission	Primary: numeric pain score (NPS) 24 h after initiation of infusion Secondary: NPS reduction at 48 h, opioid requirements measured in oral morphine equivalents, ICU and overall length of stay, epidural placement rate, pulmonary and other complications.	No observed differences between groups in NPS at 24 h. Planned sub-group analysis of patients with ISS > 15 demonstrated decreased oral morphine equivalents among patients receiving low-dose ketamine compared to controls
<i>Operative Management</i>					
Tanaka et al. (2002)	Randomized controlled trial (N = 37)	Adult patients >14 years old requiring mechanical ventilation due to severe flail chest and acute respiratory failure Exclusions: patients NOT requiring mechanical ventilation, <6 rib fractures, patients WITHOUT acute respiratory failure, closed head trauma (AIS > 3 with unconsciousness) or spinal injury, preexisting cardiac, pulmonary, hepatic or renal disease.	Surgical stabilization with Judet struts 5d after admission Internal pneumatic stabilization via mechanical ventilation *Prior to randomization, all patients received mechanical ventilation epidural anesthesia, pain management, bronchoscopic aspiration, postural drainage, respiratory physiotherapy, and antibiotics	Outcomes: incidence of pneumonia, tube thoracostomy, and tracheostomy 7- and 21-days following injury, total medical expense, ICU length of stay, duration of mechanical ventilation, 3-month pulmonary function tests, 12-month survey	Decreased incidence of pneumonia at 21 days, ICU length of stay, tracheostomies, and total medical expense among patients treated with surgical fixation compared to internal pneumatic stabilization. Additionally, patients with surgical fixation had significantly better pulmonary function tests and quality of life at follow-up.
Granetzny et al. (2005)	Randomized controlled trial (N = 40)	Patients with flail chest 3 or more rib fractures with paradoxical movement Exclusions: head trauma with disturbed level of consciousness, severe multisystem trauma, fractures of only the 1 st , 2 nd , and 3 rd rib, injuries including myocardial contusion that may be adversely affected by general anesthesia	Surgical fixation of flail segment using Kirschner and/or stainless steel wire within 24–36 h after ICU admission Non-operative management with strapping and packing of flail segment using elastoplast	Outcomes: chest wall stability, ICU and overall length of stay, duration of mechanical ventilation, complications (chest infection, mediastinitis, empyema, pulmonary embolism, wound infection, chest wall deformity, scoliosis), 60-day pulmonary function tests, all-cause mortality	Decreased ICU and overall length of stay, requirements for and duration of mechanical ventilation, reduced rates of chest wall deformity, scoliosis, and chest infections, and improved forced vital capacity and total lung capacity among patients treated with surgical fixation compared to non-operative management.
Marasco et al. (2013)	Randomized controlled trial (N = 40)	Ventilator-dependent patients with flail chest and no prospect of successful weaning over the next 48 h (3 or more ribs fractured in more than 1 place producing a free-floating segment) Exclusions: >80 years old, open rib fractures, spinal injury, sepsis, severe traumatic brain injury (GCS < 10 at scene or on admission), uncorrected coagulopathy	Surgical fixation of fractures between the levels of ribs 3 and 10 using Inion OPTS resorbable plates and bicortical screws Non-operative management with best-practice ventilator management and weaning considered each morning per protocol	Primary: duration of mechanical ventilation, ICU length of stay Secondary: pulmonary complications including pneumonia (radiographic evidence with positive culture), pneumothorax, and intercostal catheter usage; rates of failed extubation, tracheostomy, noninvasive ventilation, readmission to ICU; overall length of stay and medical expense; 3-month spirometry with chest computed tomography and 3D reconstruction; 6-month Short Form 36-Item Health Questionnaire	Patients receiving nonoperative management required post-extubation noninvasive ventilation more often and for longer durations, had longer ICU stay, and trended towards higher rates of pneumonia compared to those receiving surgical fixation. Additionally, there were decreased total medical expenses associated with surgical fixation.

pain and disability significantly decreased after correctional orthopedic surgery, though functional status did not improve.

Utility of Incentive spirometry in rib fractures

Introduced by Bartlett et al. [49] in 1973, incentive spirometry (IS) is one of the most commonly utilized methods for promoting pulmonary hygiene. The goal is to promote sustained maximal inspirations to reduce the incidence of postoperative pulmonary complications by re-inflating atelectatic lungs. Incentive spirometers require patients to exert controlled negative ventilatory pressure on a mouthpiece, thereby raising plastic floats suspended in tubes (Fig. 2). According to clinical guidelines published by the American Association for Respiratory Care, this inspiratory maneuver should be performed over a period of five seconds followed by a breath-hold and normal exhalation [50]. In theory, taking such long, slow breaths exercise the inspiratory muscles, decreases pleural pressure, improves gas exchange, and promotes lung expansion [50]. In practice, however, there is wide variation among clinical approaches to incentive spirometry use with regard to duration of inhalation and breath-hold, numbers of breaths per session, frequency of sessions, as well as target inspiratory volume [51]. As the optimal use protocol remains unknown, these differences may limit the generalizability of available evidence on the efficacy of incentive spirometry.

Current data reveals mixed conclusions regarding the efficacy of IS as a therapeutic intervention in surgery patients and concerns for poor methodology in previously reported trials. Several systematic reviews have found no evidence of benefit from IS in reducing PPCs following cardiac surgery [52], thoracic surgery [53], upper abdominal surgery [54], or surgical patients, more

broadly [55,56]. Though one review reports good evidence for lung expansion modalities in reducing PPCs, the authors rated the quality of each included IS study as poor [57]. An updated Cochrane Review of IS following upper abdominal surgery concluded in 2014 that the overall evidence is neither insufficient to disprove its effectiveness nor sufficient to recommend its widespread clinical implementation [58]. Thus, in recent guidelines, the American Association for Respiratory Care does not recommend the routine, prophylactic use of postoperative IS in hospitalized patients [50]. However, there is limited evidence to support the use of IS in nonsurgical patients [59], and there are no reported trials evaluating the efficacy of IS in patients with rib fractures specifically.

Despite a paucity of evidence, IS remains a key component of pulmonary hygiene and bundled care following rib fracture [33]. Though IS has not been evaluated specifically as a therapeutic modality, achieved IS volume has been proposed as a possible metric for evaluating respiratory function after rib fracture. As elderly patients may be more likely to underreport pain due to altered pain perception or neurocognitive deficits, some have advocated for incentive spirometry performance concurrently with pain assessment to evaluate respiratory compromise [60]. In one study, patients with four or more rib fractures were marked as high-risk if they met any of the following criteria: pain rated >6 on a numerical scale, presence of a cough, and inspiratory volume less than 15 mL/kg achieved with an incentive spirometer. The authors observed that referral of these high-risk patients to a multidisciplinary team of nurse practitioners, respiratory therapists, physical therapists, and occupational therapists was associated with a reduced number of days receiving mechanical ventilation and decreased ICU and hospital lengths of stay [61]. Similarly, Brown and Walters advocated for increased nursing documentation of incentive spirometry to more accurately trend achieved inspiratory volumes as one modality for predicting impending respiratory decline [62]. Indeed, a recent single-center study identified that low incentive spirometry volume on admission was correlated with future need for noninvasive or invasive positive pressure ventilation [63].

Harborview Medical Center uses a Pain/Inspiratory Capacity/Cough (PIC) scoring tool (originally developed by Wellspan York Hospital, York, PA and presented at the 2014 Trauma Quality Improvement Project meeting) (Fig. 3) to evaluate all patients greater than 14 years old presenting with acute rib or sternal fractures without GCS < 13, high spinal cord injury, or current intubation [33]. The PIC scores are serially collected by nurses and recorded in each patient’s room so that all members of the care

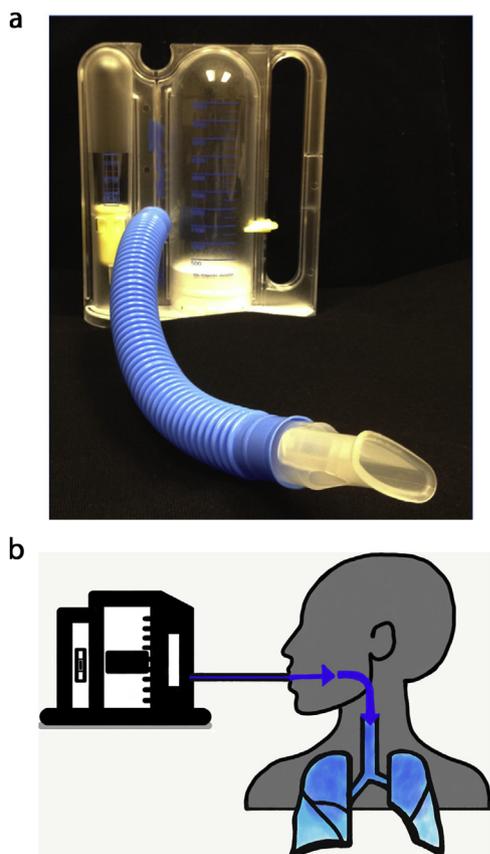


Fig. 2. (a) Photograph of a conventional incentive spirometer (IS). (b) Illustration of a patient performing a sustained maximal inspiration using an IS. (Illustration by Thomas J. Martin).

PIC Score		
1 2 3 4 5 6 7 8 9 10		
Pain	Inspiration	Cough
<small>Patient-reported, 0-10 scale</small>	<small>Inspiratory spirometer; goal and alert levels set by respiratory therapist</small>	<small>Assessed by bedside nurse</small>
3 - Controlled <small>(Pain intensity scale 0-4)</small>	4 - Above goal volume	3 - Strong
2 - Moderate <small>(Pain intensity scale 5-7)</small>	3 - Goal to alert volume	2 - Weak
1 - Severe <small>(Pain intensity scale 8-10)</small>	2 - Below alert volume	1 - Absent
	1 - Unable to perform incentive spirometry	
<small>Patient name: _____ Date: _____ IS Goal: _____</small>		

Fig. 3. PIC Score – Scoring Card. Reproduced from Witt and Bulger [33] under Creative Commons License.

team may track progress and encourage patients to use incentive spirometry as a means for improving score [33]. Patient motivation is likely an important factor in successful recovery, as compliance with prescribed IS therapy is required to realize any clinical benefit it offers. Human factors, including patients' perception of benefit from IS therapy, may be an important predictor of successful use and compliance; location of IS devices outside of patients' reach may also indicate the need for targeted intervention through patient and family education [64]. Healthcare professionals at institutions other than Harborview likely engage and assess patients using similar metrics to the PIC score, however, these methods may not be reported in the literature.

The above literature suggests the potential value of achieved IS volume as a prognostic tool to identify high-risk rib fracture patients, but the therapeutic value of IS in this population remains to be evaluated. Future studies should control for patient education, compliance, and analgesia when evaluating outcomes, as these are likely to modify the efficacy profile of IS, and should do so in a randomized, controlled manner. It should be noted that blinding this type of study may not be possible, however, as the presence or absence of an IS device will be obvious. Though a sham device could be considered as the control, one aspect of benefit from IS may originate from increasing patients' engagement and active participation in their care, such that even a sham device would provide benefit.

Conclusions

Incentive spirometry (IS) is a clinical therapy often prescribed to reduce postoperative pulmonary complications in abdominal and thoracic surgery patients, though current literature provides little evidence definitively proving or disproving its efficacy. No studies exist on the therapeutic value of IS in patients with rib fractures. However, multiple studies have demonstrated that incentive spirometry volumes may offer diagnostic and prognostic value for assessing the respiratory function of rib fracture patients, thereby allowing clinicians to identify high-risk patients and provide aggressive, multidisciplinary treatment when appropriate. Further investigation of the role of IS in the rib fracture patient population should be undertaken.

Conflicts of interest

Dr. Adam E.M. Eltorai is listed on a patent for an incentive spirometry patient reminder system but has not received any financial benefit as a result of his work (US20180000379A1); he has no other disclosures. The other authors declare no conflicts of interest.

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Author contributions

All authors contributed to the conceptualization of this review and participated in drafting, editing, and reconciling of comments related to the manuscript.

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