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Rib Trauma Value Brief

Executive Summary

Unmet Need

Multiple rib fractures can be found in up to 39% of patients after chest trauma, accounting for 10% of all trauma admissions.[1] Non-operative (conservative) treatment of severe chest wall injuries has been associated with:

- Mortality rates of 10-12% reaching as high as 35% in the most severely injured[2,3]
- Twice as high mortality and morbidity for elderly patients with similar injuries[4]
- Significant morbidity with over 50% of patients requiring ICU admission[3,5,6]
- Complication rates as high as 35% with over 33% of patients requiring discharge to an extended care facility[2,3,9]
- Prolonged disability in 66% of patients and 64% experiencing prolonged pain[10]
- No appreciable improvement in mortality and short-term morbidity since the 1980's[11]

Surgical stabilization of rib fractures (SSRF) has shown to be a potentially more effective method for rib fracture management than conservative treatment.

Clinical Evidence Supporting SSRF

Findings from 10 recently published meta-analyses strongly support benefits for SSRF patients when compared to conservative treatment with nearly all common outcomes reaching statistical significance. SSRF patients had:

- 56% to 76% lower risk of mortality[12,13]
- 4 to 7.5 fewer days of mechanical ventilation[14,15]
- 2 to 6.5 fewer ICU days[14,16]
- 3.8 to 11.4 fewer hospital days[17,18]
- 41% to 82% lower risk of pneumonia[13-15]
- 41% to 88% lower chance of tracheostomy[14,15]

Patient reported outcomes and functional outcome measures from clinical studies showed SSRF benefits relating to pain, pulmonary function, return to work and activity, quality of life, and patient satisfaction.[19-32,34] No meta-analysis or clinical study was found to have results statistically favoring conservative treatment.

Economic Implications

Based on median outcome values from 10 meta-analyses, for every 25 severe rib fracture patients (approximately 2 patients per month, annually) treated with SSRF:[7,12,13,15,16,36,37]

- Hospital costs may be reduced by $572,055*
- Potential cost-savings are attributed to reductions in the duration of mechanical ventilation, ICU days, hospital days, incidence of pneumonia, and need for tracheostomy

*Potential cost-savings determined by Zimmer Biomet as described in the section Economic Implications

Introduction

This value analysis brief presents recent clinical and economic evidence supporting surgical stabilization of rib fractures (SSRF). Patients suffering moderate to severe chest wall injury have historically been treated non-operatively (conservative) to control pain and maintain pulmonary function, including endotracheal intubation and mechanical ventilation, if necessary. The recent introduction of rib-specific rigid fixation systems has brought expanding clinical use and rapidly mounting clinical evidence showing benefits of SSRF for target patients with improvements in mortality, duration of mechanical ventilation, ICU and hospital lengths of stay, pulmonary complications, and quality of life.[7,12-18,36,37]

Methods

A search of PubMed to identify peer-reviewed literature evaluating clinical and economic outcomes of SSRF was conducted from January 2010 through May 2020. Meta-analyses, systematic reviews, randomized controlled trials, and clinical trials were considered for inclusion. In addition to the database search, a desktop search was conducted and article reference lists were reviewed to identify other relevant articles.

Background

Rib fractures resulting from chest wall trauma can present in a diverse array of fracture patterns and seriousness of injury. Single rib fractures may occur as the result of mild trauma to the chest or even as the result of strong coughing. Multiple rib fractures occur after moderate to high energy trauma to the chest and can result in a wide range of fractures types including displaced or undisplaced, unilateral or bilateral, series fractures, and flail segments without or with paradoxical motion (flail chest) and may include injury to underlying thoracic structures and respiratory failure.[38] Multiple rib fractures are common in trauma patients and can occur in up to 39% of patients after chest trauma, accounting for 10% of all trauma admissions.[1]

Typical inpatient therapy for injuries requiring hospitalization includes non-operative treatment for pain control and adequate patient ventilation. Patients not requiring hospitalization are instructed to keep their pain under control and to cough and take deep breaths to prevent the development of pneumonia. Clinicians are traditionally taught that rib fractures will heal without intervention in 6 to 8 weeks' time.[10]

In contrast, research has shown that multiple rib fractures are associated with significant mortality and thoracic morbidity and can serve as a marker for severe bodily injury with over 50% of patients requiring ICU admission.[3,5,6] Mortality increases with increasing numbers of rib fractures, reaching nearly 35% with 8 or more fractures and the mortality and short-term morbidity of flail chest injuries have not improved since the 1980's.[2,3,11] Mortality rates can be higher in elderly patients which have exhibited twice the mortality and morbidity of younger patients with similar injuries.[4] Complications such as pneumonia, pulmonary effusion, acute respiratory distress syndrome, pulmonary emboli, and atelectasis occur in as many as 35% of patients with over one-third of patients with rib fractures requiring discharge to an extended care facility.[2,3,9] Additionally, patients have demonstrated a clinically significant reduction in quality of life out to 24 months with high disability, poor return to work rates, and prolonged pain long after the acute injury.[10,27]

Unmet Need

Compared to fractures and osteotomies of other bones in the body, medical treatment of rib fractures has failed to progress at a similar rate. Even today, internal positive pressure ventilation combined with various analgesic modalities remains the most common treatment for severe chest wall injuries resulting in instability and reduced pulmonary function. Ventilatory treatment offers splinting of the chest wall during the initial stages of the healing process, but does not provide rigid fixation for fractures of the ribs.

Recently, a new option for treatment of rib fractures has emerged. Rib-specific rigid fixation systems incorporating materials and features better matched to the characteristics and properties of ribs have become commercially available. In clinical studies, SSRF has shown to be a potentially more effective method for rib fracture management than conservative treatment.[19,22,23,28,31-34]

Surgical Fixation vs Conservative (Non-operative) Management

The modern era of research studying surgical stabilization of rib fractures began around the turn of the millennium. Early studies focused on the most severely injured patients, those with unstable chest wall injuries necessitating mechanical ventilation, comparing surgical fixation to conservative medical treatment. As clinical treatment and research has progressed, study populations have also evolved to understand benefits to less severely injured patients. Four recent clinical practice guidelines consisting of one consensus statement[8], one public governing body guideline[39], and two society guidelines[7,11], considered nearly 300 publications to form expert recommendations of current best practices on SSRF indications. Careful review of clinical literature for safety and efficacy of fixation led to 5 clinical practice recommendations concerning SSRF for multiple rib fractures.

Review of nearly 300 publications led to 5 expert recommendations regarding SSRF.

Fixation should be considered in all patients with flail chest.[8]

SSRF of flail chest is conditionally recommended in adult patients based on improvement in all evaluated outcomes with consistent and sizeable treatment effects.[7]

SSRF should be considered for multiple, severe displaced rib fractures and patients who fail early conservative treatment regardless of fracture pattern.[8]

Current evidence consistently shows efficacy for SSRF of flail chest with no major safety concerns in the context of patients who have had severe trauma with impaired pulmonary function.[39]

SSRF of flail chest may be considered in severe cases that fail to wean from the ventilator or when thoracotomy is required for other reasons.[11]

A review of literature since the introduction of rib-specific fixation systems in 2010 found 12 meta-analyses and systematic reviews and upwards of 20 clinical studies of varying design. Studies and analyses reported on similar outcomes, the most common being mortality, the incidence of pneumonia and tracheostomy, the number of days spent on mechanical ventilation, ICU length of stay, and hospital length of stay.

Meta-analyses and reviews ranged in scope from inclusion of 3 high-quality RCTs to 33 studies of differing level of evidence and quality.[7,12-18,36,37,40,41] Findings substantially support benefits for SSRF patients when compared to conservative treatment for the 6 common outcomes previously described with nearly all reaching statistical significance. Findings from the meta-analyses are summarized in the following sections and details of publications are listed in Table 2.

Findings of recent clinical studies including RCTs, prospective cohort studies, and retrospective reviews are detailed in Table 3. The trials show general agreement with the meta-analyses for the previously described outcomes and introduce a number of additional findings demonstrating SSRF benefits relating to pain, pulmonary function, return to work, quality of life (QoL), and patient satisfaction with lower reported complication rates than conservative treatment.[19-35] No meta-analysis or clinical study was found to have results statistically favoring conservative treatment.

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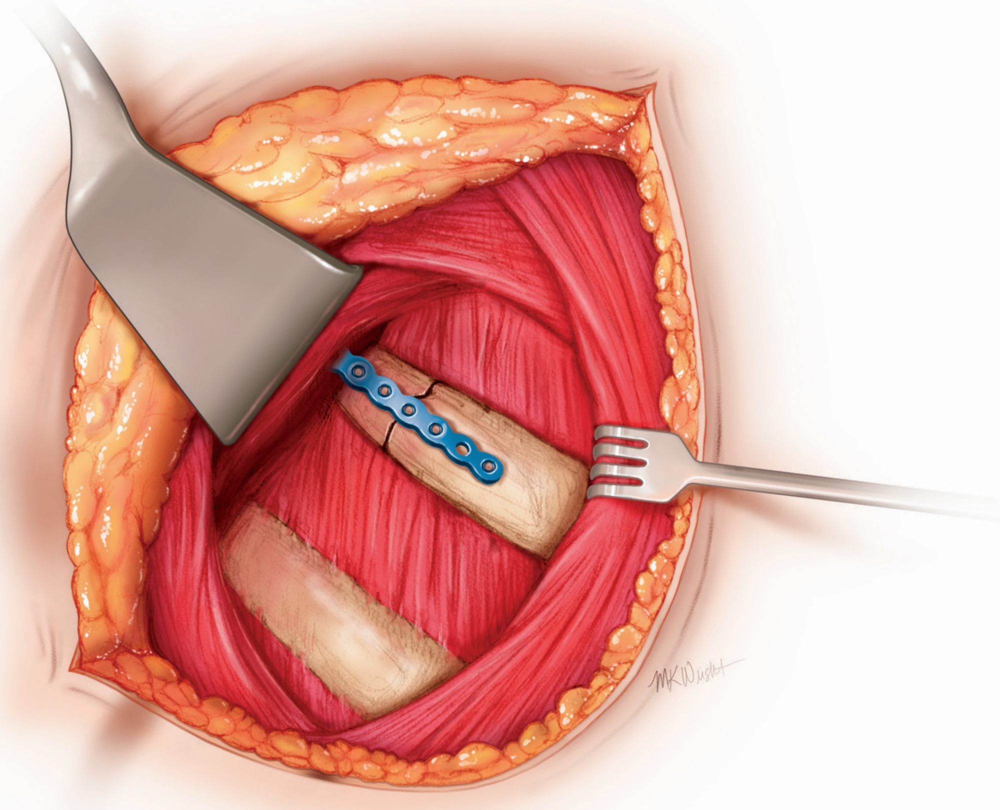


69% LOWER RISK OF MORTALITY[15]

The majority (7/10) of meta-analyses and systematic reviews found significant reductions in mortality rates for patients undergoing SSRF when compared to conservative treatment. Significant reductions ranged from 56% lower to 76% lower risk of mortality.[12,13] All meta-analyses with significant findings calculated probability of mortality reductions of greater than 50%.

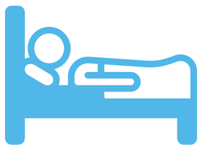
4.95 FEWER DAYS OF MECHANICAL VENTILATION[12]

All of the 9 meta-analyses reporting mechanical ventilation duration found significant reductions for SSRF patients. Reductions of invasive mechanical ventilation ranged from 4 days to 7.5 days.[14,15]

4.5 FEWER DAYS IN ICU[7, 15]

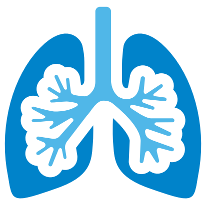
ICU length of stay was found to be significantly shorter for SSRF patients in all 10 meta-analyses. Reported reductions ranged from 2 days in an analysis with studies of varying quality to 6.5 days in a meta-analysis of only RCTs.[14,16]

Headings report median reductions based on Table 2



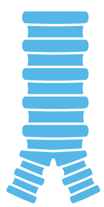
7.4 FEWER DAYS IN THE HOSPITAL[37]

Hospital length of stay was reported by 10 meta-analyses and found to be significantly shorter for SSRF patients in all but one. Reductions in hospital stay ranged from 3.8 fewer days to 11.4 fewer days in an analysis of only RCTs.[17,18] More than half (5/9) of the meta-analyses with significant findings determined the reduction in hospital stay was greater than 5 days based on the available evidence.



61% LESS RISK OF PNEUMONIA[12, 16, 36]

All meta-analyses reporting on pneumonia (10) found a significantly reduced probability for SSRF patients. Benefits for SSRF patients ranged from 41% lower to 82% lower risk of pneumonia.[13-15]



66% LESS RISK OF TRACHEOSTOMY[12]

Differences in incidence of tracheostomy was reported on by 9 meta-analyses and systematic reviews. All 9 found significant results favoring SSRF patients. SSRF patients were found to have a range of 41% lower to 88% lower risk of tracheostomy.[14,15]

Headings report median reductions based on Table 2

Significant reductions in pain were seen for SSRF patients at hospital day 7, discharge, 2-weeks, 4-weeks, and 8-weeks follow-up.[31]

Patient Reported Outcomes And Functional Outcome Measures

Pain

Despite the commonly held belief that rib fractures will heal without intervention in a time span of 6 to 8 weeks, research has shown that rib fractures can significantly displace over time and patients frequently experience chronic pain.[5] In patients with isolated rib fractures followed for at least 8 weeks, Fabricant et al. found that 64% (67/104) had prolonged chest wall pain and 66% (69/104) had prolonged disability.[10] Marasco et al. found chronic pain associated with rib fractures can extend to 24 months where 20% (41/206) of patients identified the thorax as the site of their moderate to severe chronic pain.[27]

In a 50-patient RCT, Liu et al. showed a significant reduction in pain for SSRF patients at one week follow-up. Patients reported lower pain scores while coughing (6 SSRF vs 8 conservative, $p = 0.029$) and deep breathing (5 SSRF vs 7 conservative, $p = 0.038$).[25] As the primary endpoint of a 110-patient hybrid RCT, Pieracci et al. showed a significant reduction in pain for SSRF patients without flail chest injury at 2 weeks (2.9 vs. 4.5, $p < 0.01$). Significant reductions were also seen for SSRF patients at hospital day 7, discharge, 4-weeks, and 8-weeks follow-up.[31] In a prospective cohort study by Khandelwal et al., SSRF patients (n = 38) reported lower pain scores (1.12 SSRF vs 4.50 conservative, $p< 0.05$; 0-10 scale) compared to control patients treated conservatively (n = 29) at 30 days despite qualifying for SSRF because of higher baseline pain scores compared to controls.[24]

Two long-term studies have demonstrated favorable reductions in pain for SSRF patients. In a 16-month follow-up survey study of 50 patients, Majercik et al. showed that 84% (42/50) of patients had no chronic pain. Those without pain reported that the pain had resolved at 5.4 ± 1.1 weeks post discharge. Of the 8 patients with pain, 6 reported the pain as being minimal or intermittent and not an interference with daily activities.[26] Caragounis et al. showed similar results in a 12-month prospective study of 54 SSRF patients where only 9% (4/45) of patients reported having any level of pain with breathing at one year.[20]

Pulmonary Function

Pieracci et al. conducted a prospective controlled trial of 35 SSRF patients and 35 conservatively treated patients that showed the median incentive spirometry recording per hospital day was 25% higher for SSRF patients (1,250 mL [983–1,500] vs. 1,000 mL [783–1,083], $p = 0.04$).[32] A retrospective study conducted by Peek et al. showed that in 61 SSRF patients with pulmonary function testing completed at a mean of 3 months post-operative (range 3-4 months), forced vital capacity (FVC) reached 90.2 ± 20.5% of predicted values and forced expiratory volume in one second (FEV1) reached 83.8 ± 21.3% of predicted values.[30] Caragounis et al. demonstrated similar pulmonary function findings at 3 months with significant increases in FVC and peek expiratory flow (PEF) from 3 months to one year suggesting that SSRF patients continue to improve over this time (19.8 ± 14.1% predicted increase in FVC, $p = 0.0002$; 28.5 ± 20.4% predicted increase in PEF, $p < 0.0001$).[20]

Only 59% of conservatively treated patients working prior to their injury had returned to work by six months with no change at 24 months.[27]

Patient Reported Outcomes And Functional Outcome Measures

Return to Activity

Prolonged disability in rib fracture patients can have significant consequences for society in terms of productivity and patient well-being. Fabricant et al. observed that 66% (69/104) of patients with isolated rib fractures without SSRF were affected by prolonged disability, defined as a decrease in one or more levels of work or functional status at 2 months.[10] Results from Marasco et al. found only 59% (106/181) of conservatively treated patients working prior to their injury had returned to work by six months. The rate did not change at 12 or 24 months and the authors concluded that failure to return to work by 6 months predicted failure to return to work for the next 18 months as well.[27] In a prospective comparison of SSRF to conservative rib fracture treatment, Khandelwel et al. reported a 28-day decrease in time required to return to normal activity for SSRF patients (26.62 days SSRF vs 54.21 days conservative, $p < 0.0001$).[24] In the survey conducted by Majercik et al., 92% (33/36) of employed SSRF patients had returned to full-time work at the same job in a mean time of 7.9 ± 1.0 weeks.[26]

Quality of Life

For those sustaining multiple rib fractures without SSRF, Marasco et al. found that results of the 12-Item Short Form Health Survey were significantly lower compared to published norms at all time points for physical component scores and mental component scores over the course of 24 months.[27] Caragounis et al. found that on a scale of 0 to 1, QoL of SSRF patients progressively increased from 0.78 at 6 weeks to 0.93 after 12 months using a health-related quality of life questionnaire, EQ-5D-3 L, which authors noted was higher than the reference population. Significant decreases were seen in the proportion of patients experiencing problems with mobility (27%, $p = 0.022$), self-care (36%, $p = 0.0005$), performance of usual activities (55%, $p = 0.0001$), and pain or discomfort (27%, $p = 0.035$) from 6 weeks to 1 year after surgery.[20] Pieracci et al. showed significant improvement in respiratory disability-related quality of life at 2-weeks for SSRF patients (21 SSRF vs. 25 conservative, $p = 0.03$; lower scores indicate less disability).[31]

Patient Satisfaction

Majercik et al. recorded patient satisfaction after SSRF on a scale of 1 to 10, with 1 being not satisfied at all, and 10 being very satisfied. Patients rated their experience with SSRF and the results of the procedure as 9.2 ± 0.2. Ninety-two percent (46/50) of patients said that they had no significant limitations in any part of their lives and 94% (47/50) of patients said that they would recommend SSRF to a friend or family member with a similar injury.[26]

Economic Implications

In 2002, Tanaka et al. were among the first to undertake investigation of SSRF for fractures associated with flail chest in a RCT of 37 patients. In addition to clinical benefits for patients, the authors found that total medical expenses significantly favored the SSRF patients with a cost savings approaching $10,000 per patient ($13,455 ± $5,840 SSRF vs $23,423 ± $1,380 conservative, $p < 0.05$).[42] Similar cost savings for SSRF were experienced by Marasco et al. in a RCT of 46 patients with flail chest injuries ($14,443 per patient).[28] Bhatgnagar et al. developed an economic model comparing costs of conservative treatment of flail chest to SSRF utilizing 2010 Medicare reimbursement costs for diagnoses and procedures and saw that mean cost effectiveness for SSRF reached values of >$10,000 per patient with varying quality of life improvement factors.[43] Cost effectiveness of SSRF was echoed by Swart et al. in a 2017 simulation based on the results of an accompanying meta-analysis. Even with holding clinical outcomes and long-term quality of life equal in each group, the authors concluded that the simulation results were robust over an extremely wide range of input values, and made a compelling case for more aggressive surgical management.[13]

Table 1 details potential reductions in complications and hospital resource utilization and their associated economic savings for 25 rib fracture patients (approximately 2 patients per month) undergoing SSRF in place of conservative treatment. For a fair and balanced analysis, median values of the 10 summarized meta-analyses (Table 2) including data on patients with flail chest injuries and multiple rib fractures provide the reduction factors for deaths,[15] mechanical ventilation,[12] ICU days,[7,15] hospital days,[37] incidence of pneumonia,[12,16,36] and need for tracheostomy[12]. Costs for complications and resource utilization are derived from the 2017 economic simulation by Swart et al.[13] SSRF treatment of 25 patients with flail chest or multiple rib fractures can potentially result in a cost-savings of $572,055 when considering median reductions in complications and resource utilization based on recently published data.

SSRF treatment of 25 patients with flail chest or multiple rib fractures can potentially result in a cost-savings of $572,055 when considering median reductions in complications and resource utilization based on recently published data.*

*Potential cost-savings based on median reductions in complications and hospital resource utilization from 10 meta-analyses with costs derived from Swart et al. 2017.

Table 1. Cost-savings and clinical benefits for 25 SSRF patients based on reductions in complications and hospital resource utilization.

	CLINICAL BENEFIT	COST-SAVINGS
Deaths Prevented	1.5	N/A
Days of Mechanical Ventilation Saved	123.8	$188,348
ICU Days Saved	112.5	$225,000
Hospital Days Saved	185.0	$129,500
Cases of Pneumonia Prevented	7.2	$26,369
Tracheostomy Procedures Prevented	7.1	$2,838
TOTAL PER 25 PATIENTS		$572,055

Reductions in hospital resource utilization and pulmonary complications for SSRF patients has shown to provide an overall cost-savings for patient care in multiple studies.[13,28,42,43]

Discussion

Contrary to a common belief that rib fractures will heal without intervention in 6 to 8 weeks' time, literature has shown that patients with flail chest injuries and multiple severe rib fractures suffer from chronic pain, low return to work and activity rates, and a lower than normal quality of life.[5,10,27] The introduction of rigid fixation systems better matched to the anatomy and properties of ribs was accompanied by a rise in interest to study the benefits of SSRF compared to non-operative, conservative management.[44]

The findings of 10 meta-analyses[7,12-18,36,37] and 9 clinical studies[19,22,23,25,28,31-34] demonstrate a strong clinical benefit for SSRF patients with no meta-analysis or clinical study finding results statistically favoring conservative treatment. Significant improvements in the rate of mortality, duration of mechanical ventilation, ICU and hospital lengths of stay, incidence of pneumonia, and need for tracheostomy were common trends among all meta-analyses and clinical studies. Additional outcomes showed SSRF may reduce pain, improve pulmonary function, increase rates of return to work and activity, improve short and long-term quality of life, and lead to a high rate of patient satisfaction.[20,24-26,30-32]

While much of the early evidence for SSRF has focused on the most severely injured patients, those with ventilator-dependent flail chest injuries, a new study by Pieracci et al. has shown that less severely injured patients may benefit from reductions in pain, narcotic usage, and pleural space complications with SSRF also.[31]

Reductions in hospital resource utilization and pulmonary complications for SSRF patients has shown to provide an overall cost-savings for patient care in multiple studies.[13,28,42,43] Median reduction factors for resource utilization and complications with SSRF derived from the 10 meta-analyses summarized in this value analysis brief demonstrated a potential cost-savings over $572,000 for 25 patients with flail chest or multiple, displaced rib fractures (Table 1).

This value analysis brief supports a role for SSRF as a preferred option for treatment of patients with rib fractures based on the strong evidence of efficacy in reducing complications, improving patient recovery, and reducing hospital resource utilization.

Table 2. Outcomes reported in recent meta-analyses and systematic reviews showing clinical benefits for SSRF patients.

	Study Description	Mortality	DMV (Days)	ICU LOS (Days)	HLOS (Days)	Pneumonia	Tracheostomy
Liang et al. 2019[12]	8 study meta-analysis (4 RCTs); 300 surgical patients vs 314 conservative patients	OR 0.24 95% CI, 0.07–0.87 p = 0.03	WMD −4.95 95% CI, −7.97 to −1.94 p = 0.001	WMD −4.81 95% CI, −6.22 to −3.39 p < 0.001	WMD −7.25 95% CI, −10.76 to −3.73 p < 0.001	OR 0.41 95% CI, 0.27–0.64 p < 0.001	OR 0.34 95% CI, 0.20–0.57 p < 0.001
Beks et al. 2019[14]	33 study meta-analysis (3 RCTs); 1,255 surgical patients vs 4,619 conservative patients	R 0.41 95% CI, 0.27-0.61 p < 0.001	MD -4.01 95% CI, -5.58 to -2.45 p < 0.001	MD -2.0 95% CI, -3.61 to -0.38 p = 0.02	MD -1.46 95% CI, -4.31 to 1.39 p = 0.32	RR 0.59 95% CI, 0.42-0.83 p = 0.002	RR 0.59 95% CI, 0.36-0.90 p = 0.01
Liu et al. 2019[37]	14 study meta-analysis (2 RCTs); 407 surgical patients vs 432 conservative patients	OR 0.28 95% CI, 0.08–0.92 p = 0.04	MD -4.68 95% CI, -5.62 to -3.75 p < 0.00001	MD -2.28 95% CI, -3.26 to -1.31 p < 0.00001	MD -7.40 95% CI, -8.51 to -6.28 p < 0.00001	OR 0.25 95% CI, 0.16–0.39 p < 0.00001	OR 0.14 95% CI, 0.06–0.36 p < 0.0001
Swart et al. 2017[13]	20 study meta-analysis (3 RCTs); 576 surgical patients vs 1,057 conservative patients	RR 0.44 (± 0.09) p < 0.05	WMD −4.57 (± 0.59) p < 0.05	WMD −3.25 (± 1.29) p < 0.05	WMD −4.84 (± 1.98) p < 0.05	RR 0.59 (± 0.10) p < 0.05	RR 0.52 (± 0.07) p < 0.05
Kasotakis et al. 2017[7]	22 study meta-analysis (3 RCTs); 334 surgical patients vs 652 conservative patients	OR 0.3 95% CI, 0.18–0.50 p < 0.001	WMD −6.07 95% CI, −9.27 to −2.89 p < 0.001	WMD −4.21 95% CI, −6.72 to −1.69 p = 0.001	WMD −7.63 95% CI, −11.75 to −3.51 p < 0.001	OR 0.24 95% CI, 0.13–0.46 p < 0.001	OR 0.24 95% CI, 0.12–0.50 p < 0.001
Schuurmans et al. 2017[18]	Meta-analysis of 3 RCTs; 61 surgical patients vs 62 conservative patients	RR 0.6 95% CI, 0.1-2.4 p = 0.7	WMD −6.5 95% CI, −11.9 to −1.2 p = 0.0006	WMD −5.2 95% CI, −6.2 to −4.2 p < 0.00001	WMD −11.4 95% CI, −12.4 to −10.4 p < 0.00001	RR 0.5 95% CI, 0.3-0.7 p = 0.05	RR 0.4 95% CI, 0.2-0.7 p < 0.05
Coughlin et al. 2016[16]	Meta-analysis of 3 RCTs; 61 surgical patients vs 62 conservative patients	RR 0.57 95% CI, 0.13-2.52 p = 0.46	MD -6.30 95% CI, -12.16 to -0.43 p = 0.04	MD -6.46 95% CI, -9.73 to -3.19 p = 0.0001	MD -11.39 95% CI, -12.39 to -10.38 p < 0.00001	RR 0.36 95% CI, 0.15-0.85 p = 0.02	NR
Cataneo et al. 2015[36]	Systematic review of 3 RCTs; 61 surgical patients vs 62 conservative patients	RR 0.56 95% CI, 0.13-2.42 p = 0.7	NR	285 S vs 448 C p = 0.03 (Hours)	11.7 S vs 23.1 C p < 0.001	RR 0.36 95% CI, 0.15-0.85 p = 0.05	RR 0.38 95% CI, 0.14-1.02 p = 0.05
Slobogean et al. 2013[15]	11 study meta-analysis (2 RCTs); 753 total patients	OR 0.31 95% CI, 0.20–0.48 p < 0.05	MD -7.5 95% CI, -5.0 to -9.9 p < 0.05	MD -4.8 95% CI, -1.6 to -7.9 p < 0.05	MD -4.0 95% CI, -0.7 to -7.4 p < 0.05	OR 0.18 95% CI, 0.11–0.32 p < 0.05	OR 0.12 95% CI, 0.04–0.32 p < 0.05
Leinicke et al. 2013[17]	9 study meta-analysis (2 RCTs); 219 surgical patients vs 319 conservative patients	RR 0.43 95% CI, 0.28-0.69 p < 0.05	MD -4.52 95% CI, -5.54 to -3.50 p < 0.05	MD -3.40 95% CI, -6.01 to -0.80 p < 0.05	MD -3.83 95% CI, -7.12 to -0.54 p < 0.05	RR 0.45 95% CI, 0.29-0.67 p < 0.05	RR 0.25 95% CI, 0.13-0.47 p < 0.05

DMV = duration of mechanical ventilation; ICU = intensive care unit; LOS = length of stay; HLOS = hospital length of stay; RCT = randomized controlled trial; OR = odds ratio; WMD = weighted mean difference; RR = risk ratio;MD = mean difference; NR = not reported; S = surgical treatment; C = conservative treatment.

Table 3. Outcomes reported in recent clinical studies showing benefits for SSRF patients.

	Study Description	Mortality	DMV (Days)	ICU LOS (Days)	HLOS (Days)	Pneumonia	Tracheostomy
Liu et al. 2019[25]	Prospective RCT; 25 surgical patients vs 25 conservative patients	16% S vs 8% C p = 0.67	7 S vs 9 C p = 0.012	10 S vs 12 C p = 0.032	21 S vs 22 C p = 0.44	48% S vs 80% C p = 0.038	40% S vs 28% C p = 0.55
Fitzgerald et al. 2017[22]	Retrospective matched review; 23 surgical patients vs 50 conservative patients	0% vs 4% C no test	NR	8 S vs 12 C no test	18 S vs 17 C no test	0% S vs 14% C no test	NR
Pieracci et al. 2016[32]	Prospective crossover paradigm study; 35 surgical patients vs 35 conservative patients	0% S vs 0% C ns	0 S vs 5.0 C p < 0.01	6.0 S vs 9.0 C p = 0.15	13.0 S vs 16.0 C p = 0.11	20.0% S vs 31.4% C p = 0.28	14.3% S vs 45.7% C p = 0.01
Taylor et al. 2016[33]	Retrospective cohort study; 88 surgical patients vs 88 conservative patients	2.3% S vs 25% C p < 0.01	4.1 S vs 5.4 C p = 0.02	5.2 S vs 7.4 C p = 0.09	16.7 S vs 18.5 C p < 0.01	18.2% S vs 30.7 % C p = 0.05	11.4% S vs 23.9% C p = 0.02
Jayle et al. 2015[23]	Prospective cohort with historical control; 10 surgical patients vs 10 conservative patients	NR	3.1 S vs 5.9 C p = 0.026	9.0 S vs 12.3 C p = 0.076	21.7 S vs 32.3 C p = 0.024	NR	NR
Wu et al. 2015[34]	Prospective RCT; 75 surgical patients vs 89 conservative patients	1.3% S vs 5.3% C p = 0.045	3.7 S vs 9.5 C p = 0.037	8.2 S vs 14.6 C p = 0.041	15.3 S vs 26.5 C p = 0.039	6.7% S vs 19.1% C p = 0.036	5.3% S vs 7.9% C ns
Marasco et al. 2013[28]	Prospective RCT; 23 surgical patients vs 23 conservative patient	0% S vs 4% C p = 0.87	6.3 S vs 7.5 C p = 0.37	13.5 S vs 18.7 C p = 0.03	20 S vs 25 C p = 0.24	48% S vs 74% C p = 0.07	39% S vs 70% C p = 0.04
Althausen et al. 2011[19]	Retrospective case control study; 22 surgical patients vs 28 conservative patients	NR	4.1 S vs 9.7 C p = 0.007	7.6 S vs 9.7 C p = 0.018	11.9 S vs 19.0 C p = 0.006	4.6% S vs 25% C p = 0.047	13.6% S vs 39.3% C p = 0.042
		Numeric Pain Score	**Narcotic Equivalents**	**Respiratory Disability -Related QoL**	**Overall QoL**	**Pleural Space Complications**	
Pieracci et al. 2020[31]	Patients <u>without</u> flail chest; 51 surgical patients vs 59 conservative patients	2.9 S vs 4.5 C p < 0.01	0.5 S vs 1.2 C p = 0.05	21 S vs 25 C p = 0.03 *Lower = Better*	5 S vs 5 C p = 0.17 *Higher = Better*	0% S vs 10% C p = 0.02	

DMV = duration of mechanical ventilation; ICU = intensive care unit; LOS = length of stay; HLOS = hospital length of stay; RCT = randomized controlled trial; S = surgical treatment; C = conservative treatment; NR = not reported; ns = not significant; QoL = quality of life.

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