# Current concepts in rib fracture fixation

*Rib fracture fixation by orthopaedic and cardiothoracic surgeons has become increasingly popular for the treatment of chest injuries in trauma. The literature, though mainly limited to Level II and III evidence, shows favourable results for operative fixation. In this paper we review the literature and discuss the indications for rib fracture fixation, surgical approaches, choice of implants and the future direction for management. With the advent of NICE guidance and new British Orthopaedic Association Standards for Trauma (BOAST) guidelines in production, the management of rib fractures is going to become more and more commonplace.*



## INTRODUCTION

Rib fractures are common following blunt thoracic trauma. Simple rib fractures are managed conservatively with analgesia and physiotherapy. However, between 6% and 15% of patients who sustain blunt thoracic trauma have a flail segment or multiple rib fractures.[1] These patients commonly develop respiratory failure due to inadequate ventilation secondary to mechanical failure and pain. This group are also associated with a high mortality rate and prolonged mechanical ventilation.[1-3]

A flail chest is at the more severe end of the spectrum and is defined as the fracture of three or more consecutive ribs at multiple sites, resulting in paradoxical chest wall movement.[1-3] Patients presenting with a flail chest associated with other injuries carry a high mortality risk, and, as would be expected, respiratory compromise clouds decision-making in the polytrauma setting.

## MANAGEMENT OF FLAIL CHEST AND MULTIPLE RIB FRACTURES

Historically, management for rib fractures including flail chest and multiple rib fractures is conservative, consisting of analgesia, ventilatory support and pulmonary hygiene.[4] Several methods of operative fixation have been described since the 1950s. Other non-surgical techniques are described to stabilise the thoracic cage by means of external traction, in order to restore normal breathing mechanics.[5] These early interventions were experimental at best, and despite initial interest they failed to gain enough to obtain entry into the surgical subconscious.

Non-surgical techniques to manage flail chest which have been described in the past include external traction using adhesive tape or towel clips (Fig. 1), internal pneumatic stabilisation (Fig. 2) and patient positioning. However, all are associated with complications such as prolonged bed rest, pressure ulcers, protracted mechanical ventilation, secondary chest infections and persistently high mortality rates.[5] In addition, some patients treated non-operatively report a high rate of painful fracture nonunion or symptomatic chest wall deformity.[5]

Moving on from these early attempts, a range of internal fixation options have been popularised with almost every option from locked internal plates through to intramedullary splints and 'Judet' style plates. A range of randomised and other studies have been reported to support the use of the newer evolution of rib stabilisation devices. The outcomes of these studies demonstrate that operative fixation of the flail chest is associated with improved outcomes such as reduced duration of mechanical ventilation (DMV), intensive care unit length of stay (ICULOS), hospital length of stay (HLOS), mortality rate and incidence of pneumonia. To date, the majority of publications to support this are cohort or case-control studies.[6-16] Only three randomised controlled trials (RCT) are reported in the literature (Tables I and II).[17-19]

Marasco et al[17] conducted an RCT of 40 patients with traumatic flail chest, which reported a significantly shorter ICULOS ($p = 0.03$), DMV ($p = 0.01$) and a reduced rate of tracheostomy ($p = 0.04$) in 20 patients with operative rib fixation using Stryker (Kalamazoo, Michigan) Inion OTPS resorbable plates.

Granetzny et al[18] randomised 40 patients with flail chest into two groups: non-operative and operative. The non-operative group was treated with an adhesive plaster splint and mechanical ventilation. The operative group was treated with surgical fixation between 24 and 36 hours after admission. Operative fixation was achieved using stainless steel wire fixation with or without intramedullary Kirschner wires (K-wires). Their results showed reduced duration of mechanical ventilation (two *vs* 12 days $p < 0.001$), intensive care unit length of stay (9.6 *vs* 14.6 days $p < 0.001$), hospital length of stay (11.7 *vs* 23.1 days $p < 0.001$) and incidence of chest infection (10% *vs* 50% $p < 0.014$).[18]

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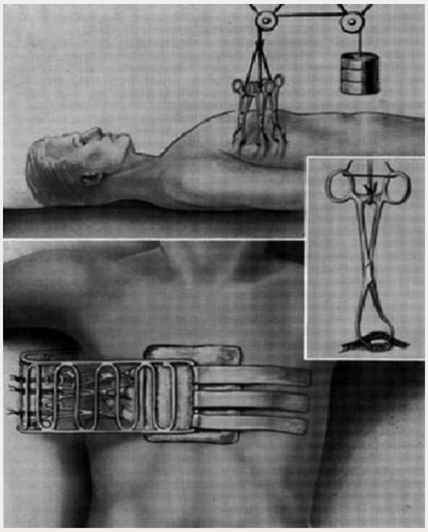

**Fig. 1** Rudimentary chest wall traction.[19]



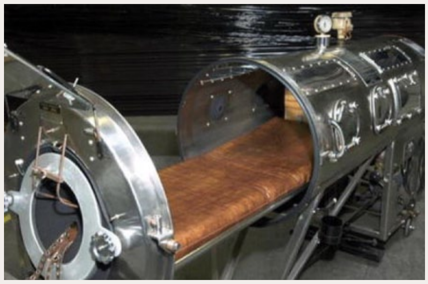

**Fig. 2** Drinker respirator or 'iron lung'. The negative pressure ventilation was thought to help with reduction of the chest wall.



Tanaka et al[20] have also reported their own randomised controlled trial and demonstrated improved outcomes with operative fixation of flail chest in their randomised controlled trial of 37 patients (18 of whom were treated operatively). Surgical stabilisation was achieved using Judet struts within 14 days of injury. Their results showed reduced DMV (10.8 *vs* 18.3 days $p < 0.05$), ICULOS (16.5 *vs* 26.8 days $p < 0.05$), incidence of pneumonia at 21 days (22% *vs* 90% $p < 0.05$), rate of tracheostomy and better recovery in lung function at three months as shown by spirometry.[20]

While these studies were sufficient for the National Institute for Health and Care Excellence (NICE) to recommend surgical stabilisation of the chest wall for patients with a flail chest, they certainly leave a lot to be desired in terms of numbers. A recent meta-analysis[21] by our group has shown that operative fixation is favoured for the majority of end points; however, there is certainly scope for more research on this new and evolving treatment.

The literature as it stands supports the use of stabilisation; however there are a range of unanswered questions, particularly surrounding the operative technique and selection of those patients who are suitable for surgery.



**Table I.** Summary of studies in English comparing operative and non-operative treatment of flail chest or multiple rib fractures[6-14,17-18,20]

| First author | Country | Studies | Results | No. of patients | |
|---|---|---|---|---|---|
| | | | | Operative | Non-operative |
| Ahmed[6] | UAE | Cohort | Reduction in DMV, ICULOS, incidence of pneumonia, sepsis, tracheostomy and mortality rate | 26 | 38 |
| Karev[7] | Ukraine | Cohort | Reduction in DMV, incidence of pneumonia, mortality rate | 40 | 93 |
| Voggenreiter[8] | Germany | Cohort | Reduction in DMV, incidence of pneumonia | 20 | 22 |
| Balci[9] | Turkey | Cohort | Reduction in DMV, mortality and incidence of pneumonia | 27 | 37 |
| Nirula[10] | USA | Case control | Reduction in DMV | 30 | 30 |
| Althausen[11] | USA | Case control | Reduction in ICULOS, DMV, HLOS, incidence of pneumonia, tracheostomy, reintubation and home oxygen requirement | 22 | 28 |
| de Moya[12] | USA | Case control | Reduced analgesia requirement, no significant difference in DMV, ICULOS, HLOS | 16 | 32 |
| Borrelly[13] | France | Cohort | Reduction in DMV and mortality | 79 | 157 |
| Marasco[17] | Australia | RCT | Reduction in ICULOS, % received NIV post-extubation, duration of NIV post-extubation, tracheostomy rate, incidence of pneumonia | 23 | 23 |
| Granetzny[18] | Germany; Egypt | RCT | Reduction in DMV, ICULOS, HLOS, incidence of pneumonia, chest wall deformity, improved three-month spirometry | 20 | 20 |
| Tanaka[20] | Japan | RCT | Reduction in DMV, ICULOS, incidence of pneumonia at 21 days, tracheostomy, improved three-month spirometry, better questionnaire score (chest pain, chest tightness, employment history, subjective dyspnoea) | 18 | 19 |

RCT, randomised controlled trial; DMV, duration of mechanical ventilation; ICULOS, intensive care unit length of stay; HLOS, hospital length of stay; NIV, non-invasive ventilation

**Table II.** Non-English articles comparing operative and non-operative treatment of flail chest or multiple rib fractures[14-16]

| First author | Country | Studies | Results | No. of patients | |
|---|---|---|---|---|---|
| | | | | Operaative | Non-operative |
| Ohresser[14] | France | Cohort | Reduction in dyspnoea at one year | 57 | 32 |
| Kim[15] | France | Cohort | Reduction in DMV and mortality rate | 18 | 45 |
| Teng[16] | China | Cohort | Reduction in DMV, intensive care unit length of stay, hospital length of stay, incidence of pneumonia and chest wall deformity | 32 | 28 |

DMV, duration of mechanical ventilation
Data obtained from abstract of article and systematic reviews which included these studies

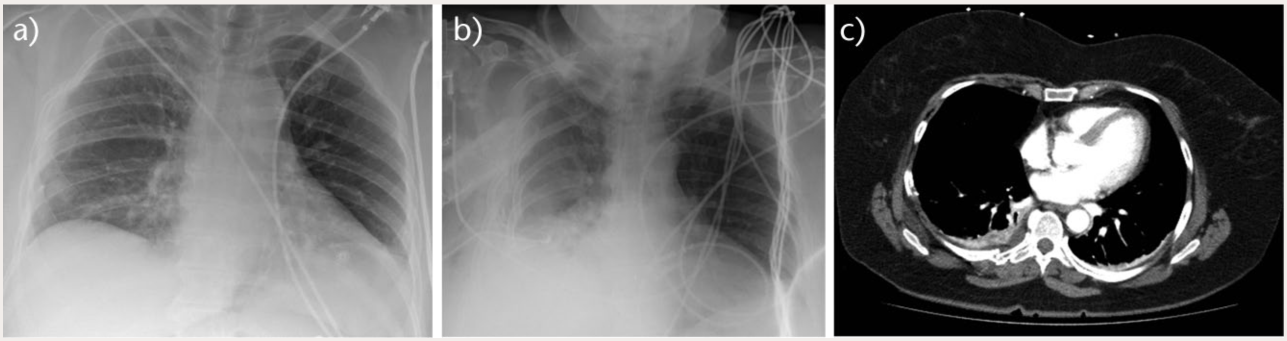


**Fig. 3** a) Initial radiograph showing right-sided flail chest on admission; b) Radiograph taken two days later showing secondary collapse and loss of volume; c) Cross-sectional CT scan on admission demonstrating posterior fractures and a flail chest.



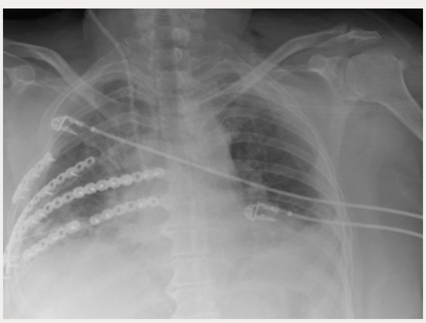

**Fig. 4** The patient shown in Fig. 3 following stabilisation of the chest wall.

## INDICATIONS FOR FIXATION

The indications for rib fracture fixation are not well established. A number of indications have been proposed including presence of a flail segment, inadequate analgesia or failure of conservative management (development of respiratory failure) associated with multiple rib fractures, chest wall deformity, chronic symptomatic non-union and thoracotomy for other indications.[22-23]

### *Flail chest*

Flail chest is perhaps the most common indication for rib fracture fixation, and superficially the easiest on which to agree. The classical definition of fractures of three or more consecutive ribs at multiple sites, resulting in paradoxical chest wall movement may not be fit for purpose when selecting patients for surgery. We prefer to define a flail chest as mechanical instability in the chest wall severe enough to hamper ventilation. This broader definition includes patients with bilateral fractures and a floating anterior chest wall, and those with multiple segmental fractures, or multiple fractures at the head or neck of the rib, all of which results in a mechanical instability but are not covered by the 'traditional' definition of flail chest.

Studies have reported good short-term results for rib fracture fixation in flail chest, and positive outcomes include a reduction in DMV, ICULOS, HLOS, incidence of pneumonia and mortality rate. However, there are conflicting results for medium- and long-term outcomes.[6-18,20,22-23]

### *Inadequate analgesia / failure of conservative management*

Pain from multiple rib fractures can prevent mobilisation, adequate respiratory effort and cough. There is plenty of evidence to support the use of strong analgesia or neuraxial analgesia.[24,25] These modalities, however, all have a relatively short duration of just a few days, and in some cases patients may still be in significant pain despite the use of supportive measures and invasive analgesia. Several authors have suggested pain as a relative indication for fixation, and given the association between rib fractures, pain, poor ventilation and respiratory complications such as pneumonia, it seems appropriate that in patients in whom the use of neuraxial analgesia cannot control their pain that surgical stabilisation ought to be offered. There is some evidence in the literature for this approach, and de Moya et al[12] reported reduced analgesia requirements in patients who underwent rib fracture fixation. Nevertheless, there is definitely room for further studies to investigate the beneficial effects and outcomes of fixation for acute pain management.[22,23]

### *Chest wall deformity*

Direct crush injury to the thorax can result in deformity of the thoracic cage and a resultant loss of thoracic volume. Severe displacement may also damage underlying lung parenchyma or other structures. Rib fracture fixation in this group of patients aims both to restore thoracic

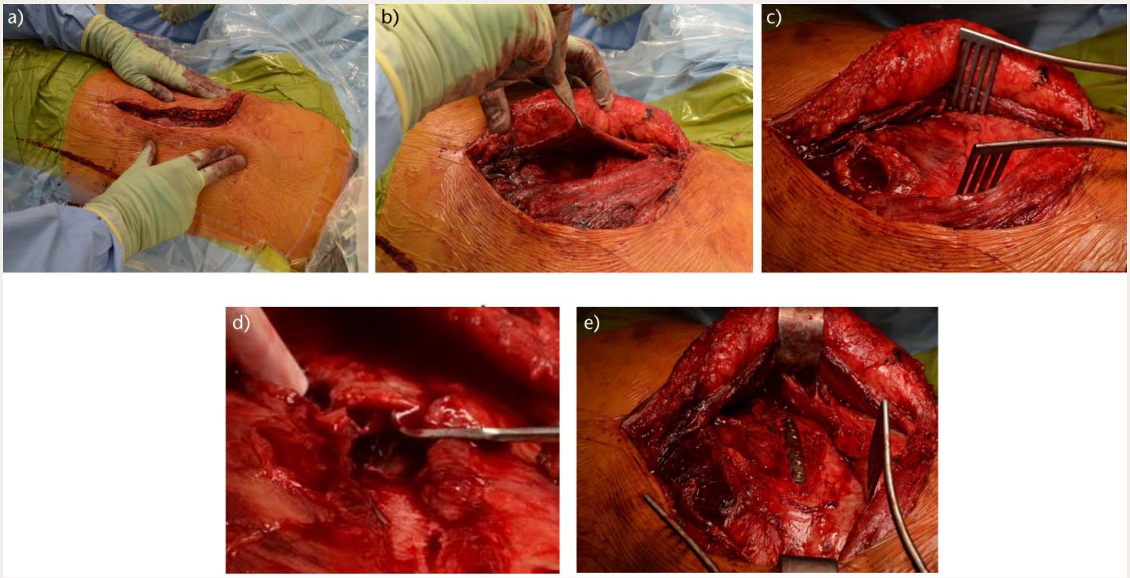


**Fig. 5** Surgical approach to the ribs. a) Extensile incision for lower para-trapezius approach; b) Muscle plane between trapezius and latissimus dorsi; c) Serratus anterior visible between the plane; d) Rib fracture identified; e) Locking plate *in situ* stabilising the ribs.

volume and prevent further damage.[22,23] Patients benefitting from this approach are small in number. However, in the severely damaged chest wall (Fig. 3 a-c) at presentation, and in patients who go on to develop significant volume compromise secondarily, there is clearly a benefit to chest wall stabilisation (Fig. 4).

### *Chronic symptomatic malunion or nonunion*

Malunion or nonunion of rib fractures may cause chronic pain and morbidity. This is more common in conservatively managed rib fractures which are initially significantly displaced. Although rarely undertaken, this can be treated surgically with internal fixation and osteotomy where required.[22,23]

Although osteotomy for malunion and for chest wall deformity is commonly performed, there is little evidence to support its use in routine practice, and the authors would not recommend undertaking lightly such significant surgery. If the correct patients are selected for primary fixation, there should be little need to correct secondary deformities. Nonetheless, nonunion is not uncommon and patients do present with persistent pain. These patients should be treated like any other long bone nonunion with a careful consideration of the risks and benefits of surgery. The nonunion itself can be treated like any other, and clinicians should undertake a full work-up including optimisation of risk factors and appropriate 3D imaging. Operative stabilisation can be achieved as it would for any other nonunion.

### *Thoracotomy for other indications*

Patients who undergo thoracotomy for other injuries may also be suitable candidates for rib fracture fixation. Often the underlying trauma is as a result of the rib fractures themselves. Fixation can be performed relatively easily at the end of the procedure and prevents potential further damage to the underlying structures.[22-23]

## TECHNIQUES AND SURGICAL APPROACHES

Both plain radiography and a CT scan of the chest are essential for the diagnosis and pre-operative planning of rib fracture fixation. When available, 3D volume rendering of the CT images can be helpful.[22,23]

Several surgical approaches have been described in the literature. These include posterolateral thoracotomy, muscle-sparing thoracotomy, the axillary approach and the inframammary approach with pectoralis lifting.[26] When planning the approach, it is key to understand the position of the fractures from the imaging, paying particular attention to accessing both fractures of each rib in a flail segment. It is not always enough to fix only the more easily accessed anterior fractures as this will not restore the function and volume of the thorax. That said, it is not necessary to stabilise all of the fractures, and often fixing alternate ribs will be sufficient to stabilise the flail and restore continuity and function of the chest wall.

Deciding which ribs need fixing is a combination of weighing up the fracture pattern, associated lung contusion, parenchymal lacerations, and likely stability of the fracture. Typically, the fourth rib is the highest accessible rib for plate fixation. It is possible to access the third rib posteriorly, though intramedullary fixation may be easier to achieve in practice. The eighth rib is usually the lowest which commonly needs to be stabilised, and it is extremely rare for there to be an indication to attempt fixation of the floating ribs (the 11th and 12th in most people). A careful plan of operative approach is required, usually with the aid of axial or volume-rendered CT scans to establish the fracture configuration and best surgical access. Even when using muscle-sparing approaches, access to the chest wall causes some surgical trauma, and in addition adds to the stress response. Judicious fixation of selected ribs can achieve a stable chest wall.

Posterolateral thoracotomy and muscle-sparing thoracotomy (Fig. 5) are performed in the lateral decubitus position, with the ipsilateral arm on a prop above the head to bring the scapula superiorly and anteriorly onto the chest wall. Both of these approaches provide good access to anterior, lateral and posterior rib fractures. The axillary approach provides access to anterior and anterolateral fractures, whereas the inframammary approach provides access to far anterior and superior fractures.[26]

For fixation with plates or Judet struts, a wide field of access is required. Posterior fractures can be fixed using an intramedullary splint allowing for a relatively minimal approach, thereby lessening the amount of soft-tissue dissection required, or directly via a paraspinal approach.[19,22,23,26]

Rib fracture fixation should be performed by an experienced surgical team capable of performing a thoracotomy, repairing underlying pleura or parenchyma if necessary, and able to deal with any complications which may arise. Most commonly in the UK the operation is performed by orthopaedic surgeons, cardiothoracic surgeons or both in combination.

## IMPLANTS

The earliest surgical techniques for rib fracture fixation involved intramedullary K-wires and heavy sutures, but these techniques were associated with implant failure, hardware migration and rotational instability. Non-locking plate fixation was also used in the past, but due to cyclic thoracic wall movement during respiration, there was a high rate of screw loosening and hardware failure. Implants have since been developed specifically for rib fracture fixation.[19,22,23,26]

### *Judet strut*

A Judet strut is a metal plate with tongs which grab the rib superiorly and inferiorly. Tanaka et al[20] reported good results with 18 patients who underwent rib fracture fixation using Judet struts for flail chest in their RCT. However, the inferior tongs have a risk of injuring the intercostal neurovascular bundle leading to chronic pain.[19,20,22,23,26]

### *U plate (RibLoc)*

The RibLoc (Acute Innovations, Hillsboro, Oregon) is a U-shaped implant which grasps the rib over its superior surface and which also has locking screw holes on the anterior and posterior limbs of the implant. It has several advantages including secure fixation of the implant which does not rely on bone quality, no damage to the intercostal neurovascular bundle and it can be implanted with minimal dissection. [19,20,22,23,26] On the other hand, the plates are not suitable for contouring and can only really be used effectively with short segment fractures.

### *Locking plates*

Early experiences of rib fracture fixation using locking plates have reported superior results with no incidence of screw cut-out or implant failure. Different sizes have been used, including 2.4 mm, 2.7 mm and 3.5 mm reconstruction plates. However, these plates require intra-operative contouring to fit the curvature of the rib surface. This can increase the complexity and operative duration of the procedure.[19,22,23,26]

Modern anatomically contoured plates such as MatrixRIB (DePuy Synthes, Warsaw, Indiana) have been developed in recent years, based on implants used in maxillofacial surgery. The plate is pre-contoured to the curvature of the rib with multiple plates available depending on the level of the rib, and is secured using bicortical locking screws. Pre-contouring significantly reduces intra-operative time, which is crucial in patients who are critically injured.[19,22,23,26,27] It is preferable for the plate to be slightly under-contoured so that the rib is reduced onto the plate. This allows the 'spring' of the plate to act to maintain the volume of the thoracic cavity. In many institutions the pre-contoured locking plate has become the implant of choice.

### *Intramedullary splints*

Intramedullary splints have been developed to achieve fixation of posterior rib fractures which would otherwise need to be fixed through more extensive dissection. Intramedullary splints allow minimal access to fractured posterior ribs and to higher ribs, particularly when trying to access high posterior third rib fractures. The splint is usually secured to the rib with one locking screw.[19,22,23,26,27] Although widely available, there are some anecdotal reports of migration or perforation through the rib, outside of the area under direct vision intra-operatively.

### *Bioabsorbable plates*

Bioabsorbable plates are used to prevent long-term stress shielding of the fracture site[28] and have the added advantage of resorbing, precluding the patient from requesting implant removal. Good results are reported with their use for anterior and lateral fractures in the literature.[17,29] However, they are not recommended for use in fixation of posterior fractures, as high rates of implant failure have been reported.[29,30] Evidence for use is currently limited and requires further investigation. There are also reports of adverse tissue reactions and sinus formation for bioabsorbable implants, which should be borne in mind when considering this implant.[31]

## FUTURE DIRECTION

Current literature and guidance from NICE support rib fracture fixation in carefully selected patients. The guidance note from NICE states, "Current evidence on insertion of metal rib reinforcements to stabilise a flail chest wall is limited in quantity but consistently shows efficacy. In addition, there are no major safety concerns in the context of patients who have had severe trauma with impaired pulmonary function".[32]

The literature is lacking in Level I evidence, with no large, well-designed randomised controlled trials to support the results and investigate the various aspects of rib fracture fixation including indications, timing of surgery, approach, implant choice and cost implications. There are several randomised controlled trials (NCT02094807, NCT01367951, NCT02132416, NCT01147471) currently underway,[33] and their results are eagerly awaited.

## CONFLICT OF INTEREST

None declared.

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