3D volume rendered Computed Tomography application for follow up fracture healing and volume measurements pre and post SRF

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Abstract

Background

Surgical rib fixation [SRF] is being used increasingly in trauma centres for stabilization of chest wall injuries, in line with new and evolving surgical techniques. Our institution has developed a pathway for the management of chest wall injuries and SRF, which includes a follow up low volume, non-contrast Computed Tomography (CT) scan at 12 months.

Methods

This study was a single centre retrospective study was conducted on 25 consecutive patients who underwent SRF between February 2019 to February 2020. All CT measurements were done by a CT radiographer under the supervision of a board-certified radiologist and included the use of 3DVR images.

Results

There were no patients with SRF who experienced hardware failure at 12 months in either flail or non-flail groups. For fractured ribs treated with SRF, complete or partial union occurred in 75/76 [98.7%] of ribs plated. The median ratio for improvement in lung volumes was 1.71 for flail SRF and 1.69 for non-flail SRF in our study.

Conclusion

3DVR CT at 12 months post SRF showed good alignment [no hardware failure] and fracture healing of fixed ribs in both flail and non-flail groups. Lung volumes also improved pre and post SRF for both flail and non-flail patients. More studies are needed to define how the pattern of rib fracture healing of fixed and non-fixed ribs affects lung volumes.

Level of Evidence: Level III

Study Type: Prognostic Original Study

Keywords: Surgical Stabilisation of Rib Fractures, 3D Volume rendered Computed Tomography, Lung Volumes

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Background

Rib fractures are a common injury in trauma patients, occurring in about 30% of polytrauma patients.1 Surgical rib fixation [SRF] is increasing being used in trauma centres for stabilization of chest wall injuries, in line with new and evolving surgical techniques.2 The goal of stabilizing fractures must be balanced with the ability to maintain breathing mechanics and not create a restrictive chest wall with excessive fixation.3 Whist there is evidence supporting fixation of flail chest injuries associated with respiratory compromise4, other indications for surgical intervention are less clear. These include fixation of non-flail injuries, fracture patterns that will most benefit from SRF, and how many ribs to surgically fix at a time.

The Chest Wall Injury Society [CWIS] has recently developed some guidelines for rib fixation which include non-flail indications.5,6 Follow up Computed Tomography( CT)-lung volume estimates have shown improvements for patients undergoing stabilizing surgery for flail chest injuries, with a strong correlation between post-operative CT lung volume and lung function tests.7 Non-contrast CT has also been used to study fracture healing at 3 months post rib fixation for flail chest injuries, showing that the philosophy of fixing only one rib per flail segment does not avoid deformity and displacement, particularly in posterior rib fractures.8

Our institution has developed a pathway for the management of chest wall injuries and SRF, which includes a follow up low dose, non-contrast CT scan at 12 months. The object of this paper was to review the 12-month CT outcomes of SRF based on CWIS guidelines, including both flail and non-flail rib fracture patterns, treated as part of a standardized pathway within our institution. Specific objectives include the incidence of hardware failure, fracture healing of fixed and non-fixed ribs, and the effect on lung volumes.
Methods

This study was a single centre retrospective study was conducted on 25 consecutive patients who underwent SRF between February 2019 to February 2020 at Gold Coast University Hospital [GCUH], a 750 bed Level 1 Trauma Centre in South East Queensland. Following application to the local Human Research Ethics Committee the need for ethical approval was waived as this was deemed a quality activity.

Rib Fracture Protocol

Patients ≥ 18 years old requiring hospital admission for chest injuries had a CT chest with arterial phase contrast in the Emergency Department [ED]. For patients with rib fractures involving any of ribs 4-8, a 3D volume rendered [3DVR] reconstruction was performed to assist the surgeon to assess the pattern and severity of the injuries. A standardized blunt trauma pathway was initiated on admission including a patient-controlled analgesia pump started in the ED, and early Acute Pain Service referral for consideration of a regional block [paravertebral, erector spinae or epidural].

Our local institution indications for SRF were based on the CWIS guidelines which include chest wall instability, loss of lung volume on CXR or CT and pulmonary derangement. Chest wall instability was defined as three or more rib fractures involving the 4th to 8th ribs which were offset >50% or displaced [no cortical contact] on axial CT imaging [including flail and non-flail patterns]. Pulmonary derangement for non-ventilated patients was defined as an elevated respiratory rate, incentive spirometry < 50% predicted for patient, poor cough and pain not controlled despite Acute Pain Service input within 72 hours. Failure to wean from the ventilator due to rib fractures was also an indication for acute fixation. The aim was always to operate as early as possible after the time of injury [within 72 hours]. No chronic
rib fracture injuries were included in the cohort. All rib fixations were performed using the same titanium fixation plating system [RibLoc U Plus Chest Wall Plating System®, Acumed LLC, Hillsboro, Oregon, USA]. Anaesthesia is conducted with single lumen tube by non-cardiothoracic anaesthetists.

Post discharge follow up for SRF patients included outpatient review at 4 weeks with a CXR, and a low dose non-contrast CT thorax at 12 months performed either in our institution or an imaging centre local to the patient if from out of area. Patients were contacted via phone for results of the CT and further review as required.

Rib fracture/injury pattern description was as per CWIS consensus of taxonomy for multiple rib fractures.

Outcome Measures
All CT measurements were done by a CT radiographer with 12 years of CT experience under the supervision of a board-certified radiologist and included the use of 3DVR images. Outcome measures on CT at 12 months included hardware failure, fracture healing and assessment of lung volumes. Hardware failure was defined as screw migration, plate migration and plate fracture. Fracture healing was assessed for plated and non-plated ribs as previously described by Marasco et al. Bone union was classified into the following groups: complete union, partial union, non-union and bridging callus between adjacent ribs or adjacent screw fixation plates. Deformity of non-fixed ribs was grouped as: overlap [AP displacement and shortening of length], angulation > 15 degrees and displacement [superior/inferior non-continuity]. The occurrence of maladaptive callus formation representing callus and bony bridging between adjacent ribs was also noted if present.
Phillips IntelliSpace Portal [version 7.0] software was used for automatic measurement of lung volumes, a process that has previously been validated by other studies\(^1\). Figure 1 illustrates the software-generated results for lung volume measurement from thin-slice CT images. The tissue defined as lung is visualised in colour 3D and multiplanar reconstruction. Automatic volume measurements of this tissue are tabulated simultaneously in the adjacent window. Lung tissue was defined as the sum of voxels with attenuation less than 950 Hounsfield Units. The accuracy of automatic segmentation was evaluated in axial, coronal and sagittal planes by the operator and manually corrected as required. Pneumothorax and haemothorax tissue volumes were manually included in the measured lung volume as to accurately describe the thoracic contour available for lung expansion. Lung volumes were obtained pre-SFT fixation and at 12-month follow-up. Comparison was performed between affected and non-affected sides; and for flail and non-flail subjects.

All statistical analysis was performed using Stata/SE 16.1 statistical package (Stata Corp. LP, College Station, TX). Descriptive statistics results are shown as means ± Standard Deviation [SD] for continuous variables and n and % for categorical variables.

In comparing the flail and non-flail groups a t-test was used for continuous data. If the assumptions of this test were not met, the appropriate test (Mann Whitney U test) was applied. The 95% confidence intervals (CIs) are calculated for the flail group. A \( P \) value less that 0.05 was considered significant.

The ratio of calculated affected side lung volume post SRF at 12 months was compared to the pre-operative affected lung volume. Lung volumes were analysed using box plot analysis method to illustrate median and interquartile ranges.
Results

Patient demographics are shown in Table 1. Mechanism of injury was similar in the flail and non-flail groups, with a higher overall ISS in the flail group.

Follow-up was 100% complete at 12 months, but one patient was excluded from analysis due to inability to obtain a full set of CT images.

Description of rib fracture patterns on pre-operative CT and number of fixed ribs for both flail and non-flail patients is shown in Table 2. Two patients in the flail group had bilateral rib fractures, with rib fixation done unilaterally in all cases on the most severely affected side. Only one patient, in the non-flail group, had rib fixation without evidence of offset or displaced fractures in the 4-8 region. This patient had 6 fractured ribs [5th -10th] associated with severe pain not responding to standardized pain management by our Acute Pain Service. Not all displaced or offset fractures in the 4-8 rib zone were surgically fixed, with 2 patients in the flail and 2 in the non-flail having some but not all ribs plated in this region. There were 10 patients who had SRF outside the 4-8 rib zone: 6 in the flail and 4 in the non-flail groups. All patients had a single additional rib plated outside those performed in the 4-8 zone.

Hardware failure was not observed on follow up 3DVR CT in either flail or non-flail groups. A summary of rib fracture healing and deformity post fixation is presented in table 3. For fractured ribs treated with SRF, complete or partial union occurred in 43/44 of ribs plated in the flail group and 32/32 ribs plated in the non-flail group, with overall complete or partial union in 75/76 [98.7%] of ribs plated. In the one case with no union, alignment across the fracture site was maintained by the surgical plate.
Follow-up CT showed complete or partial union in 19/27 [70.4\%] of offset or displaced ribs not treated by SRF.

Residual deformity [overlap, angulation >15 degrees or superior/inferior displacement] of ribs in the 4-8 zone not treated with SRF occurred in 3 patients in the flail group and 3 patients in the non-flail group in table 3 [involving 4 ribs in the flail group and 7 ribs in the non-flail group].

Maladaptive callus causing bridging between adjacent fractured ribs occurred in 4/25 [16\%] of patients: 3/12 [25\%] in the flail chest fixation group and 1/13 [7.7\%] in the non-flail group. All maladaptive callus formation in the flail group occurred between adjacent plated ribs [see figure 2 for example]. The only non-flail patient with this finding had callus bridging from a plated rib to an adjacent non-plated rib.

The ratio of improvement in lung volumes of the affected side post fixation to lung volume prior to fixation are shown for flail and non-flail injuries in figure 3. This showed a median 1.7 improvement [Q1=1.39, Q3=1.88] for patients post SRF of flail side and 1.695 [Q1=1.54, Q3=2.08] improvement post SRF of non-flail injuries.

**Discussion**

3DVR CT is commonly used in the pre-operative planning of rib fixation, allowing an easily grasped understanding of the relevant anatomy, the nature of problem at hand and the scale of the surgical challenge\(^2\). We included this as part of our clinical practice for long term follow up of patients to assess for hardware failure, chest wall stability and effect on lung volumes, which is useful when assessing patients for complications such as chronic pain and need for
further intervention. There was no evidence in our study of long-term hardware failure identified on CT using external titanium plates [RibLoc]. Sarani et al \textsuperscript{11} performed a multi-centre study of 1,224 patients and reported a hardware failure rate of 3\% of SSRF patients, although routine follow up imaging was not performed in this study. Marasco et al\textsuperscript{8} reported a hardware failure rate of 9.6\% on follow up 3D VR CT at 3 months, although all these failures were with patients fixed with absorbable plates.

For displaced or offended fractures treated with SRF there was good evidence of fracture healing with 98.7\% of patients having complete or partial healing on follow up CT at 12 months. Combined with the fact there was good alignment of fractures [no hardware failure] SRF used in this way adds long term stability for the key ribs involved in respiration [4-8 zone]. There was a lower rate of healing [70.4\%] in offset or displaced ribs that were not plated, however residual deformity occurred equally in flail and non-flail patients with 3 patients in each group. Marasco et al\textsuperscript{8} also demonstrated maladaptive callus causing bridging between adjacent ribs in their CT follow up study of flail chest SRF, occurring 54\% of rib fractures not fixed and in 23\% of fixed fractures [all in patients fixed with absorbable plates]. This contrasts with our study which showed such callus formation in 16\% of patients, all of which involved the inserted titanium plates. The use of titanium plates would seem to reduce but not eliminate such maladaptive callus formation. The true significance of such callus formation is unknown, but if extensive such callus could potentially restrict chest wall movement and affect lung expansion.

Caragounis et al\textsuperscript{7} demonstrated that for flail chest injuries, lung volume increased from a median of 3.5 litre pre-op to 5.59 litre post-op [ratio 1.55]. This compares to a median ratio improvement of 1.71 for flail SRF and 1.69 for non-flail SRF in our study. Improvement in
the absolute volume of lung in litres is likely to be greater for a larger patient than for a smaller patient. A ratio of post-operative to pre-operative lung volume may address the confounding effect of body habitus. Due to a heterogeneous group of patients and a small sample size, we reported the ratio of improvement for each patient instead of absolute volume improvement. The exact relationship however between the pattern of fracture healing and how this affect lung volumes has not been defined and requires further investigation.

Limitations
Our study has limitations inherent to retrospective cohorts, small number and single institution. We could not identify and match patients without rib fractures to serve as a control. Chest wall injuries are very heterogeneous to describe and patients often have a combination of fracture patterns, making accurate description of healing patterns difficult to compare. Lung volume estimates on 3DVR CT are affected by the depth of inspiration during image acquisition, which in turn is limited by other factors including pain. Respiratory function tests were not performed pre-SRF (in non-intubated patients) and on follow-up, as this could have added another layer of objectiveness on the advantages of SRF.

Conclusion
In the setting of traumatic rib fracture, 3DVR CT at 12 months post SRF showed better rib healing in both flail and non-flail groups and no evidence of hardware failure. SRF showed lung volume recruitment in patients with flail and non-flail rib fractures. More studies are needed to define how different devices, the pattern of rib fracture and healing of fixed and non-fixed ribs affects lung volumes and patient outcome.
Author Contributions

Don Campbell    - Literature search, data interpretation, writing and critical revision
Nicholas Arnold  - Literature search, data collection and data interpretation
Elizabeth Wake  - Literature search, data interpretation, writing and critical revision
John Grieve     - Study Design, data collection and data interpretation
Sylvio Provenzano - Critical revision
Martin Wullschleger - Study Design
Bhavik Patel    - Study Design, Literature search, data interpretation and critical revision

Conflicts of Interest

There are no conflicts of interest

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10 Hyun-ju Lim, Oliver Weinheimer, Mark O. Wielpütz, Julien Dinkel, Thomas Hielscher, Daniela Gompelmann, Hans-Ulrich Kauczor, Claus Peter Heussel. Fully Automated Pulmonary Lobar Segmentation: Influence of Different Prototype Software Programs onto Quantitative Evaluation of Chronic Obstructive Lung Disease *PLOS ONE.* DOI:10.1371/journal.pone.0151498

Figure Legends

Figure 1 – CT lung volume measurement

Figure 2 - Bridging Callus formation

Figure 3 - Results for Pre- and post-SRF lung volumes
Table Legends

Table 1 - Patient Demographics

Table 2 - Rib Fracture patterns

Table 3 – Rib Fracture Healing Characteristics
Figure 1: CT lung volume measurement: lung tissue visualised in colour 3D and multiplanar reconstruction.
Figure 2: Maladaptive callus post SRF occurring between surgical plates [arrow]
Figure 3: Lung volumes post SRF
### Table 1: Patient Demographics

<table>
<thead>
<tr>
<th></th>
<th>All n=25</th>
<th>Flail n=12</th>
<th>Non-Flail n=13</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>52.8 (14.06)</td>
<td>55.15 (14.8)</td>
<td>50.25 (13.34)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Male</td>
<td>18 (72%)</td>
<td>9 (69.2%)</td>
<td>9 (75%)</td>
</tr>
<tr>
<td><strong>ISS</strong></td>
<td>18.52 (10.61)</td>
<td>22.92 (12.5)</td>
<td>13.75 (5.2)</td>
</tr>
<tr>
<td><strong>Mechanism of Injury</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fall</td>
<td>7 (28%)</td>
<td>4 (30.77%)</td>
<td>3 (25%)</td>
</tr>
<tr>
<td>- MVA*</td>
<td>2 (8%)</td>
<td>1 (7.69%)</td>
<td>1 (8.33%)</td>
</tr>
<tr>
<td>- MBA*</td>
<td>9 (36%)</td>
<td>4 (30.77%)</td>
<td>5 (41.67%)</td>
</tr>
<tr>
<td>- Push bike</td>
<td>5 (20%)</td>
<td>3 (23.08%)</td>
<td>2 (16.67%)</td>
</tr>
<tr>
<td>- Heavy transport</td>
<td>1 (4%)</td>
<td>1 (7.69%)</td>
<td>0</td>
</tr>
<tr>
<td>- Other transport</td>
<td>1 (4%)</td>
<td>0</td>
<td>1 (8.33%)</td>
</tr>
<tr>
<td><strong>Length of Hospital Stay (days)</strong></td>
<td>10.91 (8.63)</td>
<td>12.9 (10.63)</td>
<td>8.75 (5.42)</td>
</tr>
</tbody>
</table>

*ISS – Injury Severity Score; MVA - motor vehicle accident; MBA - motor bike accident
† Mean and Standard Deviation
¥ n and %
Table 2: Rib fracture injury characteristics

<table>
<thead>
<tr>
<th></th>
<th>All patients n = 25</th>
<th>Flail Chest n=12</th>
<th>Non-flail Chest n=13**</th>
<th>95% CI (Flail)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior rib fractures*</td>
<td>16 (66.7%)</td>
<td>12 (100%)</td>
<td>4 (33.33%)</td>
<td>(0.47-0.92)</td>
<td>--</td>
</tr>
<tr>
<td>Lateral rib fractures*</td>
<td>24 (100%)</td>
<td>12 (100%)</td>
<td>12 (100%)</td>
<td>(0.29-0.70)</td>
<td>--</td>
</tr>
<tr>
<td>Anterior rib fractures*</td>
<td>10 (41.67%)</td>
<td>7 (58.33%)</td>
<td>3 (25%)</td>
<td>(0.34-0.93)</td>
<td>--</td>
</tr>
<tr>
<td>Rib fracture variables:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of ribs offset/displaced</td>
<td>2.8 [1.7]</td>
<td>3.3 [1.5]</td>
<td>2.2 [1.7]</td>
<td>(2.34-4.32)</td>
<td>0.098</td>
</tr>
<tr>
<td>involving ribs 4-8†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of ribs fixed‡</td>
<td>3 [0.93]</td>
<td>3.5 [0.79]</td>
<td>2.42 [0.67]</td>
<td>(3.07-4.08)</td>
<td>0.000</td>
</tr>
</tbody>
</table>

* Reported as n and %
† Reported as mean and Standard Deviation [SD]
** Data obtained for 12/13 patients in flail chest cohort

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### Table 3: Rib Fracture Healing Characteristics

<table>
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<tr>
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<th>Flail n=12</th>
<th>Non-Flail n=13</th>
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<tbody>
<tr>
<td>Fracture healing ribs treated with SRF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Total</td>
<td>44</td>
<td>32</td>
</tr>
<tr>
<td>- Complete union</td>
<td>33</td>
<td>23</td>
</tr>
<tr>
<td>- Partial union</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>- Non-union</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fracture healing non fixed ribs previously offset or displaced 4(^{th}) to 8(^{th}) ribs:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Total</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>- Complete union</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>- Partial union</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>- Non-union</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Fracture healing outside 4(^{th}) to 8(^{th}) ribs previously offset/displaced:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Total</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>- Complete union</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>- Partial union</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>- Non-union</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Residual deformity 4(^{th}) - 8(^{th}) ribs not treated with SRF:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Total</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>- Overlap</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>- Angulation &gt; 15 degrees</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>- Superior/Inferior displacement</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Residual deformity of ribs not treated with SRF outside 4(^{th}) to 8(^{th}) ribs:</td>
<td></td>
<td></td>
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<tr>
<td>- Total</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>- Overlap</td>
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<tr>
<td>- Angulation &gt; 15 degrees</td>
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<tr>
<td>- Superior/Inferior displacement</td>
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<td>2</td>
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*SRF – Surgical Rib Fixation*