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ORIGINAL ARTICLE

Rib fracture displacement worsens over time

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Abstract

Purpose Rib fractures (RF) occur in 10% of trauma patients; associated with significant morbidity and mortality. Despite advancing technology of surgical stabilization of rib fractures (SSRF), treatment and indications remain controversial. Lack of displacement is often cited as a reason for non-operative management. The purpose was to examine RF patterns hypothesizing RF become more displaced over time.

Methods Retrospective review of all RF patients from 2016–2017 at our institution. Patients with initial chest CT (CT1) followed by repeat CT (CT2) within 84 days were included. Basic demographics were obtained. Primary outcomes included RF displacement in millimeters (mm) between CT1 and CT2 in three planes (AP = anterior/posterior, O = overlap/gap, and SI = superior/inferior). Displacement was calculated by subtracting CT1 fracture displacement from CT2 displacement for each rib. Given anatomic and clinical characteristics, ribs were grouped (1–2, 3–6, 7–10, 11–12), averaged, and analyzed for displacement. Secondary outcome included number of missed RF on CT1. Non-parametric sign test and paired *t* test were used for analysis. Significance was set at $p < 0.002$.

Results 78 of 477 patients with RF on CT1 had CT2 during the study period: primarily male (76%) and age 55.8 ± 20.1 with blunt mechanism of injury (99%). Median Injury Severity Score was 21 (IQR, 13–27) with Chest Abbreviated Injury Score of 3 (IQR, 3–4). Median time between CT1 and CT2 was 6 days (IQR, 3–12). Missed RF rate for CT1 was 10.1% ($p = 0.11$). Average fracture displacement was significantly increased for all rib groupings except 11–12 in all planes ($p < 0.002$).

Conclusion RF become more displaced over time. Pain regimens and SSRF considerations should be adjusted accordingly.

Keywords Rib fracture · Rib fixation · Pain · Displacement · Chest trauma

Introduction

Rib fractures are the most common injuries following blunt chest trauma, occurring in approximately 10% of all traumatically injured patients and approximately 50% of blunt chest trauma population [1–6]. Rib fractures are further associated with increased mortality and severe pulmonary-related

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morbidity [1–4, 6–8]. Patients with eight or more rib fractures have a mortality rate of 34.4% with more than half of these patients requiring intensive-care unit (ICU) admission [9]. Over one-third will develop pulmonary complications and one-third require discharge to an extended care facility [4, 10]. Furthermore, as the population continues to age worldwide, rib injury frequency and the associated morbidity and mortality will continue to increase as older individuals are more vulnerable and more likely to die as a result of chest injuries [7, 8, 11, 12].

Over the past decade, vast improvements have been made in the care of the rib fractured patient; however, outcomes for this patient population still remain poor and with little change [1, 3, 6]. The main clinical manifestation of rib fractures is chest wall pain, which is often the principal cause of the underlying morbidity and mortality [13, 14]. Multiple modalities have been proposed for managing rib fracture pain including both opioid and nonopioid pain medications, delivered enterally, parenterally, topically, or through regional means [13, 15–20]. Recently, surgical stabilization of rib fractures (SSRF) has gain popularity in the management of patients with rib fractures to help reduce pain and the development of associated complications. However, there still remains uncertainty about which patients would benefit from SSRF [1, 2, 6, 9, 14, 21–23].

Lack of rib fracture displacement is often cited as a reason for non-operative intervention for rib fracture patients. Review of current literature often describes "severely displaced" rib fractures as an indication for SSRF, with "severely displaced" defined as anywhere from 50% rib thickness transposition to bi-cortical displacement [1, 23–27]. Furthermore, the RibScore developed in 2015 defined "severely displaced" as displacement greater than the diameter of the rib with total loss of contact between the proximal and distal segments [28]. While many rib fracture patients present with severely displaced fractures, many do not have any signs of displacement on their initial CT. The question then becomes what happens to their rib fractures over time and would these individuals potentially benefit from SSRF earlier in their hospital course? Expansion of the thoracic cavity is a cyclically derived reflex necessary for life. It is conducted in three planes (vertical, anteroposterior, and transverse) with average adult chest expansion ranging from 3 to 5 cm on inhalation [29]. Given chest wall physiology and constant movement of the chest with inspiration and exhalation, the aim of this study was to assess rib fracture displacement over time. We hypothesized that rib fractures would become more displaced with time.

Methods

This was an Institutional Review Board approved retrospective review study. All trauma patients from 2016 to 2017 admitted to our Level I, academic trauma center with rib fractures were evaluated for the study. Basic demographics including age, gender, Injury Severity Score (ISS), Chest Abbreviated Injury Score (c-AIS), ICU and hospital length of stay, presence of a flail chest, and status of patient at discharge were further extracted from our trauma registry. ISS is an established medical score assessing the overall severity of a major trauma (greater than 15 is considered major trauma). c-AIS is an anatomic score representing just the severity of the thoracic cavity injury itself. Patients were included in the study if they had an initial chest computed tomography (CT1) followed by a second chest computed tomography (CT2) within 84 days of injury. Current literature suggests that rib fractures heal within 6–12 weeks [30]; hence, the reason 84 days was chosen for repeat CT criteria in this study. The CT2 was obtained for a variety of reasons including, but not limited to, assessment for the presence of a hemothorax or pleural effusion, to rule out a pulmonary embolism, assessment of vascular abnormality, and assessment of thoracic spine injury/repair, or to evaluate for an empyema. All patients underwent CT scanning at our institution utilizing a helical scan with 1.25 mm slices. The CT scan was obtained through the apices of the lung superiorly and the top of the kidneys inferiorly with standard reconstruction. With varying body habitus, the approximate number of CT slices was anywhere from 225 to 250 per patient.

Rib fracture displacement was then measured in millimeters (mm) in three different planes: anterior–posterior (AP), overlap or gap (O), and superior–inferior (SI). All images were digital using McKesson Radiology software (12.1.1). The site of the rib fracture served as the reference point for measurements between CT 1 and CT2, and the outer cortex of the rib was used for the measurements. Utilizing the built-in measuring software for McKesson Radiology (12.1.1), distances were obtained in the three planes, making sure to maintain the same angle for measurements between CT1 and CT2 further utilizing the angle management software built into McKesson Radiology (12.1.1).

The primary outcome of the study was the difference in displacement of the rib fractures in all three planes between CT1 and CT2. Rib displacement for each plane was calculated by subtracting the initial fracture displacement measurement (CT1) from the follow-up displacement measurement (CT2) for each rib. Given the large amount of data generated for this study, the decision was made to group rib fractures based on anatomic and clinical characteristics. Ribs were grouped as follows; ribs 1–2, ribs 3–6, ribs 7–10, and ribs 11–12. Ribs 1 and 2 are high in the rib cage and fractures here are often associated with high mortality (36%) and high likelihood of concomitant injuries given underlying structures [9, 31]. Furthermore, SSRF does not confer additional pain relief or chest wall stability. [1] Ribs 4–10 are the most commonly fractured ribs [9, 27], but we separated the groupings into 3–6, as fractures here can be under the scapula, and 7–10, as there are no additional overlying structures other than muscle obstructing these ribs. Finally, ribs 11 and 12 are free floating, and again, there does not appear to be a chest wall stabilization or pain relief benefit from SSRF of these fractures. [1] Once the displacement between CT1 and CT2 was determined, the differences amongst the rib groups were averaged and analyzed. The secondary outcome for the study was the number of rib fractures missed from CT1 to CT2. Non-parametric sign test and paired t test were used for analysis. Statistical significance was set at a *p* value of < 0.002 given multiple comparisons.

Table 1 Demographics

Variable	
Age (years)(SD)	55.8 ± 20.1
Male gender	76%
Blunt injury mechanism	99%
Injury severity score (IQR)	21 (13, 27)
Chest abbreviated injury score (IQR)	3 (3.4)
Flail segment present	36%
Average number of rib fractures on CT1	5
Average number of rib fractures on CT2	6
Median days between CT1 and CT2 (IQR)	6 (3, 12)
Hospital LOS (IQR)	13 (8, 21)
ICU LOS (IQR)	3 (0, 10)
Discharged alive	96%

IQR inter-quartile range, *CT* computed tomography, *SD* standard deviation

Results

A total of 477 patients with rib fractures on CT1 were reviewed during the 2-year study period. Only 78 of these patients met inclusion criteria having undergone a repeat chest CT within the allotted 84 days. A total of 461 rib fractures were compared between CT1 and CT2. Patients were primarily male (76%), aged 55.8 ± 20.1 years with blunt trauma serving at the primary mechanism of injury (99%). Median ISS was 21 [inter-quartile range (IQR) 13–27] with a median c-AIS of 3 (IQR, 3–4). Demographics are displayed in Table 1. Median time between CT1 and CT2 was 6 days (IQR, 3–12).

When analyzing our primary outcome, all rib groupings, expect the 11–12 group, demonstrated statistically significant increases in the displacement between CT1 and CT2 in all three planes of measurement. Rib group 11–12 did not show any increase in displacement between CT1 and CT2. Of note, there were not as may rib fractures for analysis in this group as there are for the other groupings. Table 2 demonstrates the results for the primary outcome. Upon analysis of our secondary outcome, a total of 513 rib fractures were found on CT2 (CT1 average = 5 rib fractures; CT2 average = 6 rib fractures). Therefore, CT1 missed 52 rib fractures resulting in a missed rib fracture rate of 10.1% on initial chest CT. This was not statistically significant (*p* = 0.11).

Table 2 Average rib fracture displacement

View	Grouping	Left				Right			
		n	Displacement (mm)	SD	*p* value	*n*	Displacement (mm)	SD	*p* value
AP	Ribs 1–2	22	1.201	1.069	< 0.0001	18	1.773	1.911	0.0011
	Ribs 3–6	35	1.692	1.303	< 0.0001	37	1.512	1.354	< 0.0001
	Ribs 7–10	33	1.877	1.972	< 0.0001	32	1.731	2.154	< 0.0001
	Ribs 11–12	8	0.865	0.682	NS	5	1.019	0.902	NS
O	Ribs 1–2	22	0.876	0.848	< 0.0001	18	1.474	1.253	0.0001
	Ribs 3–6	35	1.679	1.277	< 0.0001	37	2.337	3.278	0.0001
	Ribs 7–10	33	1.457	1.073	< 0.0001	32	1.470	1.411	< 0.0001
	Ribs 11–12	8	1.713	1.916	NS	5	5.099	7.017	NS
SI	Ribs 1–2	22	0.585	0.673	0.0005	18	1.780	1.893	0.0009
	Ribs 3–6	35	1.840	1.265	< 0.0001	37	1.437	1.745	< 0.0001
	Ribs 7–10	33	1.814	1.386	< 0.0001	32	1.275	1.610	< 0.0001
	Ribs 11–12	8	1.362	1.780	NS	5	1.040	1.040	NS

AP anterior/posterior view, *O* overlap or gapped view, *SI* superior/inferior, *n* number of patients, *mm* millimeters, *SD* standard deviation, *NS* not significant

Discussion

To the authors' knowledge, this is first study to examine the natural occurrence of acute rib fracture displacement over time. Our study demonstrated that all rib fractures, except fractured ribs 11 and 12, become significantly more displaced over time. Given the constant movement of the rib cage, this would intuitively make sense; however, it had never been demonstrated quantitatively until now. Furthermore, our study demonstrated a relatively low missed rib fracture rate on initial chest CT scan of only 10.1%. This is approximately half of previously described missed fracture rates of 20.7% [4, 32]. Although the exact cause of this decrease in missed fracture rate is outside the scope of this study, one could contribute this to better CT scan technology utilizing a helical scan with 1.25 mm slices.

Rib fractures can be a debilitating injury with significant morbidity and mortality. The rib cage and muscular attachments provide significant protection for an array of very important internal structures as well as provide a great deal of thoracic stability. In a recent study by Brasiliense et al., intact ribs, on average, accounted for 78% of thoracic stability [33]. Based on these findings, some authors suggest that the rib cage could represent a "fourth-column" of stability for the thoracic spine [33, 34]. Our study negatively affects this concept suggesting that as rib fractures become more displaced over time, so too may the stability of the chest wall resulting in worse complications and disability.

One of the main clinical manifestations of rib fractures is chest wall pain [13]. It has been well established in trauma literature that poorly controlled chest pain is associated with an increased risk of complications such as atelectasis, pneumonia, acute respiratory distress syndrome, and ventilator dependence which can further result in increased hospital length of stay complications, mortality, and long-term disabilities [13, 35–38]. A recent study by Bugaev et al. showed that the magnitude of rib fracture displacement and the number of rib fractures can predict opioid requirements [13]. For every 5 mm increase in total chest wall displacement, there was an increase in morphine equianalgesic dose (MED) by 6.3% [13]. Every additional rib fracture was associated with an 11.2% increase in MED [13]. This finding has significant relevance to our study. For example, if a patient with rib fractures has worsening displacement over time, in theory, this could lead to worse pain control for the patient as well as an increased need for opioids utilizing standard pain control protocols, leading to opioid overdose, hypercarbic respiratory failure, and intubation in the ICU. Furthermore, if 10% of rib fractures are missed at the initial chest CT, it is possible that standard pain control strategies may be undertreating the true severity of the injury. This, in turn, may be one of the reasons conventional pain control strategies fail over time.

Surgical fixation of rib fractures has recently been gaining popularity in the chest trauma community as another management option for patients with rib fractures [1, 6, 13, 27, 39]. Although there is a clear indication for SSRF in the flail chest patient [23, 40–42], indications for operative intervention outside this patient population still remain controversial [1, 2, 6, 9, 14, 21–24]. Consensus among the SSRF community would suggest that there is a lack of evidence for the fixation of ribs 1, 2, 11, and 12 in terms of providing additional benefit for chest wall stability or pain control except in rare circumstances and in fact, repairing ribs 1 and 2 can often prove very challenging and risky given underlying structures in that area of the thoracic cavity [1, 23, 26, 27]. For the remaining ribs, 3 through 10, a common indication for SSRF is severely displaced fractures which, as stated above, is defined as anywhere from displacement of 1/2 of total rib thickness to complete bi-cortical displacement of the fracture [1, 23–27, 39]. This definition is often based on the initial chest CT which the patient receives upon arrival.

Our study suggests that rib fractures become significantly more displaced over time. Given these findings, the authors would infer that lack of severe displacement at the time of presentation does not predict future displacement. The amount of rib fracture displacement for our study only ranged from 1.2 to 5.1 mm, but when the average thickness of a rib is 8.4 mm and the average height is 12 mm [43], the amount of displacement over time could result in severe displacement of that fracture. Furthermore, it is important to remember that the ribs change shape and thickness as they traverse the chest wall [43]. Therefore, severe fracture displacement could result with less actual displacement over time at various locations throughout the rib. For example, if a rib measured 8 mm thick and the first image of the fracture showed 3 mm displacement in the AP plane, if displacement worsened by only 2 mm, the total displacement would be 5 mm, turning this fracture into a severely displaced rib fracture by definition. This could make one re-evaluate the SSRF indication of severely displaced fractures present at admission by broadening it to include patients with mildly displaced rib fractures at presentation knowing that they may progress to severely displaced fractures over time. Furthermore, a study by Marasco et al. in 2014 qualitatively demonstrated that fixating only one rib fracture per rib in a flail segment does not necessarily avoid worsening deformity and/or displacement of the non-fixated rib fracture, especially when the non-fixated rib fracture is posterior [44]. Despite the uncertainty as to whether the worsened deformity and/or displacement was a direct result of the single fracture fixation per rib in the flail chest versus natural rib fracture healing pathophysiology, utilizing Marasco's study in conjunction with our study further strengthens the SSRF consideration in patients with initial minimally displaced fractures, especially if they have a flail chest.

Despite this being a novel study with multiple statistically significant findings supporting our hypothesis, there still are several limitations. First, this is a single center, retrospective review. Ideally, a prospective, multi-institutional study would help to alleviate institutional and healthcare provider bias. Second, this was a small-sample size. Despite reviewing 477 charts of patients with rib fractures on CT1, only 78 patients met inclusion criteria by undergoing a second CT within the 84-day time period. A larger sample size could provide more clarity in the displacement of rib fractures over time. Third, the repeat CT scan was not conducted at a specific time, rather at the discretion of the treating physician. Given this variability in the amount of time from CT1 to CT2 and our small-sample size, we were unable to determine what the ideal time frame was to maximum rib fracture displacement, as the authors feel this would be very interesting and of benefit to the reader. Thus, repeat CT scanning to determine timing of displacement is being considered in a protocol for future studies. Fourth, we did not examine the clinical relevance of increased rib fracture displacement over time. Although one can speculate, future studies are required to assess the relationship between clinical outcomes and the finding of increased rib fracture displacement. Fifth, although attempts were made at standardization between CT1 and CT2 by patient positioning and having the scan completed during inspiration, this was not always guaranteed given patient condition and/or inability to follow commands. Finally, the rib fracture groupings which we provided for our analysis may not be a true representation of each individual rib. Although these ribs do have several anatomic, physiologic, and clinical properties in common, they are all individual and could potentially be affected differently when it comes to displacement over time.

Conclusion

Rib fractures become significantly more displaced over time. Furthermore, 10% of rib fractures are missed on initial chest CT. Although the clinical relevance and specific displacement patterns have yet to be determined, the progressive displacement may result in deteriorating thoracic instability, increased rib fracture pain, or overall failed pain control protocols. Furthermore, knowing rib fracture displacement increases over time may impact the indications for SSRF. Although our conclusions are limited only to the data in this study, we are currently carrying out studies to assess the clinical and surgical relevance of this progressive rib fracture displacement over time.

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Compliance with ethical standards

Conflict of interest No authors have any conflicts of interest or financial disclosures to provide.

Ethical approval This study was approved by the appropriate ethics committee at our institution and all ethical standards were followed.

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