Missed injuries in trauma patients: the value of a diagnostic thoracotomy or thoracoscopy during surgical stabilisation of rib fractures

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Abstract

Purpose Over the last decade Surgical Stabilisation of Rib Fractures (SSFR) gained popularity in our hospital. With increased numbers, we noted that frequently injuries were missed during primary/secondary survey and radiological imaging that were found during the surgical procedure. With this observation, the research question was formulated: What is the value of diagnostics thoracotomy or thoracoscopy during surgical stabilisation of rib fractures?

Methods In a single-centre, retrospective study between February 2010 and December 2019, trauma patients who underwent Surgical Stabilisation of Rib Fractures (SSFR) and an inspection thoracotomy were included. All radiological injuries were compared with intraoperative findings. Missed injuries that were discovered during the surgical procedure that were not analysed during primary/secondary survey or on radiological imaging were recorded and retrospectively analysed by an independent radiologist.

Results Fifty-one patients were included. Eight patients had additional injuries; all had a diaphragmatic rupture, one patient had an additional stomach laceration, and another patient had a significant lung laceration in need of surgical repair. On a CT scan there are 7 signs of predictive value for a diaphragmatic rupture. Only 13 out of the total of 56 diaphragm rupture CT signs were confirmed on the primary CT scans of the eight patients with diaphragmatic injuries; therefore, still 77% of signs could not be confirmed by initial radiological findings.

Conclusion With the recent shift towards surgical stabilisation of rib fractures, an inspection thoracoscopy or thoracotomy during SSFR should be considered to minimise the incidence of missed intrathoracic injuries requiring early or late surgical treatment.

Keywords Blunt trauma · Diaphragm rupture · Missed diagnosis · Surgical Stabilisation of Rib Fractures

Background

In the last two decades, there has been a change in management of rib fractures. Benefits of surgical stabilisation over internal pneumatic stabilisation in traumatic flail chest patients has been proven [1–3]. Worldwide, Surgical Stabilisation of Rib Fractures (SSRF) has gained popularity and nowadays it is frequently performed in patients with severe chest wall injuries [4]. SSFR indication has recently been generalised to trauma patients with three or more rib fractures without flail, with optimistic results in pain scores, and self-reported respiratory disability [5]. With this shift towards surgical management, additional injuries are being diagnosed during intraoperative inspection that were not detected with primary radiological imaging. Missed injuries in trauma patients are a well-known obstacle in acute care. Incidence rates for missed injuries and delayed diagnosis range from 1.3–39% in patients suffering blunt trauma [6]. For example, despite an overall incidence of diaphragm injury of 0.46% in trauma patients [7], it has been found in 3–8% of patients undergoing surgical exploration [8]. We hypothesise that with the shift towards SSRF, an inspection through thoracoscopy or thoracotomy should be considered to diagnose otherwise missed intrathoracic injuries needing surgical intervention.
Methods

A single-centre, retrospective study was performed in a Dutch Level one Trauma Centre. All cases who underwent an exploring thoracotomy during SSRF from February 2010 till December 2019 were included. No exclusion criteria were applied. Due to the retrospective design and the anonymous processing of information and results, approval by the medical ethics committee was waived.

All radiological injuries were compared with intraoperative findings. Missed injuries that were discovered during the surgical procedure that were not analysed during primary/secondary survey or by radiological imaging were recorded. Additionally, age, sex, and Injury Severity Scale (ISS) were stated. The Injury Severity Score (ISS) at admission was formulated using the global method. The ISS is the sum of the squares of the three most severe injuries in different body regions on a 6 point scale (1 = minor injury, 6 = maximal injury) [9]. Also trauma mechanism, number of rib fractures, and other primary injuries were listed. Non-parametric statistical tests were used to estimated significance.

In retrospect, CT scans from trauma patients with missed injuries were analysed again by an independent radiologist to compare perioperative findings with the primary radiological images. Due to the lengthy time period (2010–2020) the analysed CT scans were performed on different models of CT scanners. The oldest scans were performed on a 64-slice scanner (either Toshiba Aquilion 64 or Siemens Somatom Definition AS), as the more recent scans were performed on a 256-slice Dual-Source scanner (Siemens Somatom Definition Flash). The Toshiba Aquilion 64 was installed on June 2007 and replaced with a second Siemens Somatom Definition Flash on January 2016. The first Siemens Somatom Definition Flash was installed on the Emergency ward on October 2014. Because this study was performed in a level one Trauma Centre, some patients were referred from other hospitals with CT scans made on a Siemens Somatom Definition AS with an unknown installation date. The results of the radiographic analysis were analysed in IBM SPSS Statistics, V27; due to the small numbers no tests could be performed.

All patients underwent a contrast-enhanced CT of the thorax (and abdomen) (either in the arterial or portal-venous phase, depending on the chosen scan protocol at the time of trauma) with full visualisation of the complete diaphragmatic dome. All available reconstructions were analysed (axial, coronal, and sagittal reformatted images with 2- or 3-mm slice thickness) together with all available settings (soft tissue setting, lung setting, bone setting).

Amongst other things, all scans were analysed for the various signs of diaphragmatic rupture described by Panda et al. in 2014 (see Table 1) [10]. Three specific diaphragm injury signs are as follows:

| Table 1 | The CT signs for diaphragmatic ruptures |
|---------|----------------------------------------|
| The various signs of diaphragmatic rupture described by Panda et al. |
| Discontinuous diaphragm sign |
| Collar sign |
| Dependent-viscera sign |
| Dangling diaphragm sign |
| Organ herniation or hump sign due to a partial liver herniation |
| Thickening of the diaphragm |
| Continuous injury on either side of the diaphragm |

1. **Collar sign** (the visualisation of a focal, waist-like constriction of the herniating abdominal viscus at the level of the torn diaphragm)
2. **Dependent-viscera sign** (when the upper one third of the liver abutted the posterior ribs on the right side or if the stomach or bowel abutted the posterior ribs or lay posterior to the spleen on the left side)
3. **Dangling diaphragm sign** (present if the free edge of the torn diaphragm was visible as it curled inwards towards the centre of the abdomen, away from or at near right angles to the chest wall).

The perioperative found diaphragm ruptures were classified following the description by Williams et al. (see Table 2) [11].

Results

In total 51 patients who underwent SSRF and an exploration thoracotomy or thoracoscopy were included. Indication for surgical treatment of the rib fractures differed between flail chest, haemothorax, pneumothorax, unable to detached from the ventilator, and deformation of the thorax. A total of 236 rib fractures were fixated during surgery, using 14 sutures, 28 splints, and 194 plates.

Eleven patients of the total cohort had diaphragm injuries. Three patients with diaphragm injuries were diagnosed with primary radiological examination. Eight patients of the total of 11 patients had diaphragmatic injuries that were

| Table 2 | Characteristics of diaphragm ruptures |
|---------|--------------------------------------|
| Diaphragm ruptures classified by Williams et al. |
| Grade 1: contusion |
| Grade 2: laceration < 2 cm |
| Grade 3: laceration 2–10 cm |
| Grade 4: laceration > 10 cm and tissue loss of < 25 cm² |
| Grade 5: laceration and tissue loss of > 25 cm² |
discovered by inspection during surgery. These eight diaphragmatic injuries were not analysed during primary/secondary survey or at radiological imaging prior to the surgical treatment (16.7%). The average age of all the included patients was 59 years old and 13 patients were female. The mean primary ISS at admission was 27 (range 9–57) in the complete cohort with no difference between patients with or without missed diaphragmatic injuries. The characteristics of the patients are listed below (Table 3).

All eight patients with a missed injury had a diaphragmatic rupture differ from grade 2 to grade 4. One patient had an additional stomach laceration; another patient had a severe lung laceration due to a rib perforation without pneumothorax. Three out of eight diaphragmatic ruptures were found left-sided, and five were right-sided. All missed diaphragmatic injuries were easily diagnosed during thoracic inspection through thoracotomy on the side that the SSFR took place; only one patient of the complete cohort underwent an inspection thoracoscopy with non-additional injuries due to the availability of a thoracic surgeon at the time of the SSRF procedure. Therefore, 50 patients underwent a lateral thoracotomy instead of thoracoscopy. Surgical Stabilisation of Rib Fractures was performed using the following techniques: straight plates with screws, intramedullary splints, and Vicryl sutures or a combination depending on the characteristics of the fractures. Additional diaphragm injuries were treated with sutures, the use of a surgical mesh, or a combination of both.

During retrospective inspection by an independent radiologist only 13 out of a total of 56 possible CT signs for diaphragm rupture in the eight patients with additional injuries were seen on the CT scans made during primary assessment (Table 4). From the eight patients with additional found diaphragm injuries two were scanned on the Toshiba Aquilion 64 CT scanner, four on the Siemens Somatom Definition Flash, and another two were referred from another hospital with a CT scan made on a Siemens Somatom Definition. Due to the small numbers, no statistical analysis could be performed and we concluded that there was no difference in sensitivity between the different CT scanners and the scans made during the early inclusions and recent inclusions. One patient with a grade 2 rupture of the diaphragm on the right side had no positive CT signs at all. Even after sharing the perioperative findings with the radiologist, still 77% of the signs could not be confirmed by radiological findings. All injuries that were described during primary radiological imaging were confirmed during surgery, so no false positive diagnoses were found in this retrospective study.

Mortality rates in these trauma patients turned out to be high; six of the total 51 patients (11.8%) did not survive the first month after their accident. Of the deceased patients, one had additional injuries that were not discovered during primary CT scans. It concerned patient number 4; he was involved in a car accident and had a radiologically missed diaphragmatic rupture grade 4 on the left side. Due to the severe thorax deformation, extreme obesity and an infected

| Parameters | Without additional injuries found during surgery = 43 | Additional injuries found during surgery = 8 | Total = 51 |
|------------|-----------------------------------------------------|----------------------------------|-----------|
| Men/women  | 32/11                                               | 6/2                              | 38/13     |
| Age*       | 61 years (39–83)                                    | 53 years (22–78)                 | 59.4 years|
| ISS        | 27.3 (range 9–57)                                   | 26.75 (range 9–50)              |           |
| Average number of rib fractures** | 10 (2–24) | 9 (3–13) | 9.6 |
| Trauma mechanism*** |                               |                                 |           |
| Pedestrian vs car | 3 (7)             | 0 (-)                     | 3 (6)     |
| Cyclist vs car  | 10 (24)                | 0 (-)                     | 10 (20)  |
| Car vs car     | 8 (19)                   | 4 (50)                    | 12 (24)   |
| Motorbike accident  | 2 (5)                 | 0 (-)                      | 2 (4)     |
| Fall from height | 16 (38)               | 3 (33)                     | 19 (37)   |
| Otherwise     | 4 (10)                   | 1 (11)                    | 5 (10)    |
| Primary injuries |                                                  |                                 |           |
| Pneumothorax  | 6                              | 4                        | 10        |
| Haemothorax   | 10                             | 3                        | 13        |
| Intraabdominal injury**** | 11 (1)             | 4 (0)                     | 15        |
| Neurocranial injury | 13                        | 3                        | 16        |

*Average age in years and full range of ages
**Average in rib fractures and full range of fractures
***Exact number with percentages
****Intraabdominal injury (requiring laparotomy)
seroma in the thorax he could not be disconnected from respiratory support after surgery and passed away due to sepsis.

Eighteen of the total cohort had intraabdominal injuries, with a mean primary ISS of 36 (range 18–57). Only one patient was in need of acute exploration and treatment by laparotomy. The remaining 17 were treated conservatively. Sixteen patients had some sort of neurocranial injury, with a mean primary ISS of 35 (range 17–57). Thirteen patients had a haemothorax, causing a mean primary ISS 26 (range 9–50), with an indication for surgical treatment. Five of them were identified as caused by a minor arterial injury and one by a major venous injury due to dissection of the Azygos vein. Three of the haemothorax patients were caused by a lung laceration. In four cases no clear cause was found.

**Discussion**

In our retrospective study, eight of 51 patients (16.7%) had undiagnosed diaphragm/chest/abdominal injuries during primary, secondary, and radiological examinations. This is conform previous described incidence rates. All initially missed injuries were easily detected during thoracic inspection by thoracotomy or thoracoscopy and were surgically treated during the SSFR procedure. All the initially missed injuries were categorised as major or life-threatening injuries according to Pfeiffer et al. (see Table 5), so early discovery contributes to enhancement of treatment [6]. Retrospectively only 13 out of 56 CT signs are positive for diaphragmatic ruptures, so even with the perioperative knowledge, still 77% of signs could not be confirmed by radiological findings. One patient did not have any positive CT signs at all; with the given information, one may conclude that a diaphragm rupture cannot be excluded by a negative scan in trauma patients with rib fractures. One of the possible explanations could be found in the small difference in Hounsfield Units (HU) between the diaphragm and the adjacent visceral tissue (either the liver, spleen of stomach directly beneath the diaphragm, or the (frequently seen) volume loss of the lung) on the side of the injury. In this respect, there was no clear difference between arterial and portal-venous scans. Combining this with a variable thickness of the diaphragm in both injured and healthy patients, proved to have a negative effect on visualisation of several of the described signs of diaphragm injury, especially the discontinuous diaphragm sign (without herniation) and the thickening of the diaphragm. Therefore we recommend, based on our experience, to perform a thoracic inspection during SSFR in trauma patients to prevent secondary surgical treatments and chronic complications due to missed injuries, until CT scans and techniques significantly improve to diagnose diaphragm injuries.

A missed diaphragmatic rupture tends to become larger, and herniation of abdominal organs becomes more likely, particularly if the rupture is left-sided. Small right-sided injuries may remain stable due to the liver that tamponades the defect, preventing colon herniation. Nevertheless, repair of all left-sided and most right-sided diaphragmatic injuries should be

### Table 4 Results of diaphragmatic rupture signs at CT scan

| # | Injury | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|---|
| 1 | Diaphragm rupture grade 3 left side | − | − | − | − | + | + | − |
| 2 | Diaphragm rupture grade 3 right side | − | − | − | − | + | − | + |
| 3 | Diaphragm rupture grade 4 left side | − | − | − | − | + | − | + |
| 4 | Diaphragm rupture grade 2 right side | + | − | − | − | − | + | − |
| 5 | Diaphragm rupture grade 4 right side | + | − | − | − | + | − | − |
| 6 | Diaphragm rupture grade 2 right side | − | + | − | − | + | − | − |
| 7 | Diaphragm rupture grade 2 left side and stomach laceration of 1 cm | − | − | − | − | + | − | + |
| 8 | Diaphragm rupture grade 2 right side and lung perforation < 1 cm | − | − | − | − | − | − | − |

I discontinuous sign, II collar sign, III dependent-viscera sign, IV dangling diaphragm sign, V organ herniation or liver hump, VI thickening, VII continuous injury on either side of the diaphragm, + retrospectively confirmed, − retrospectively absent

### Table 5 Missed injuries selected at level of severity

- Minor injuries: hand, wrist, foot, ankle, forearm, uncomplex soft tissue injuries and fractures, rupture of ligaments, and muscle tendons
- Major injuries: skull injuries, neurological and arterial lesions, liver, spleen, and intestinal lacerations, femoral, humeral, pelvic, and spine fractures and dislocations
- Life-threatening injuries: injuries of main vessels in thorax, haemothorax, and pneumothorax
performed when recognised due to the tendency to increase [11]. Therefore, surgical treatment becomes difficult and more complications occur, when the rupture becomes chronic. A mortality rate of 30–60% has been described in patients with intrathoracic visceral herniation and strangulation after a missed diaphragmatic injury [10]. With that, early detection of intrathoracic injuries contributes to increased survival rates and quality of life in trauma patients. Multiple studies and consensus statements have mentioned the possible benefits of adding an intrathoracic inspection during SSFR [12]. Early evacuation of residual haemothorax during thoracic inspection by thoracoscopic surgery has proven to decrease the risk of infections, discomfort, and shorten length of hospital stay amongst other advantages such as the possibility to directly repair lung lacerations and other intrathoracic injuries [13, 14]. Other studies suggest that the with the use of thoracoscopic inspection, better visualisation of the fracture locations help to determine the optimal incision placement and therefore enhance minimally invasive methods with smaller incisions sides and less muscle loss [12, 13]. A complete thoracoscopic approach has only been performed in study design and is not suitable outside the context of research due to limitations of adequate tools. Despite these potential benefits more data has to be collected to support and recommend the routine use of thoracoscopy (or thoracotomy) during SSFR [12].

This study concerns trauma patients with severe injuries, causing a mean ISS of 28 points. Because of the major injuries in this cohort, intrathoracic injuries are more likely to occur. Therefore, the incidence of missed injuries, such as diaphragm ruptures, are higher and the diagnostic value of an inspection thoracoscopic or thoracotomy increases. With the recent shift towards surgical management of rib fractures, more research will estimate the incidence of missed injuries in less severe patients.

Limitation of this study is the small number of included cases without a control population. Patients with a missed diaphragm injury were not confirmed and a long-time follow-up and secondary surgical repair of those patients could not be compared with early on surgical repair. Another limitation was the need for a thoracic surgeon with sufficient experience in Video-Assisted Thoracoscopic Surgery (VATS) to perform a thoracoscopy during SSFR; therefore, only one patient underwent a minimal invasive technique whilst almost the complete cohort underwent a thoracotomy. So difference in approach for intrathoracic inspection could not be compared.

Conclusions

With the recent shift towards surgical stabilisation of rib fractures an inspection thoracoscopy or thoracotomy should be considered during SSFR in selected patients to minimise the incidence of missed injuries requiring early or late surgical treatment.

Author contribution Reiner de Groot, Wim Hogeboom, and Pascal Steenvoorde designed the research. Tess Wemeijer and Dominique Withaar collected the data. All authors analysed the data and contributed to the writing of the manuscript.

Data availability Anonymous data set available when requested.

Declarations

Conflict of interest The authors declare no competing interests.

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