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ORIGINAL ARTICLE

Recovery after stabilising surgery for 'flail chest'

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Abstract
Background/Purpose There is a lack of knowledge on respiratory and physical function, mobility and pain following stabilising surgery for 'flail chest'. The purpose of this study was, therefore, to evaluate pain, respiratory function, range of motion and physical function/activity 3 and 6 months after stabilising surgery in patients with 'flail chest' due to trauma.
Method Twenty-four patients diagnosed with 'flail chest' were, 3 and 6 months after the trauma, measured with regard to remaining pain, lung volume, breathing movements, and range of motion in the rib cage and thoracic spine. Physical function and level of physical activity were also estimated.
Results Approximately 50 % of the patients had remaining pain after 3 months and 35 % had remaining pain after 6 months. Vital capacity was significantly decreased after 3 and 6 months compared to predicted values: >83 % after 3 months and >86 % after 6 months. There were no significant differences between the injured versus non-injured side in breathing movements, nor between the values of the range of motion between the two test occasions. The results of physical function showed mild to moderate disability 3 months after surgery and some or mild disability at 6 months. The patients were active, performing moderate exercise 1–2 h/week or light physical activities more than 4 h/week at 3 and 6 months.
Conclusions Patients who had undergone stabilising surgery due to 'flail chest' showed decreased range of motion 3 and 6 months after surgery. Despite decreased range of motion and remaining pain, the breathing movements are synchronic.

Keywords Flail chest · Range of motion · Rib cage · Ribs · Spirometry

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Introduction

In trauma to the chest, there is a risk that ribs are damaged and fractured. When multiple adjacent ribs are broken in several places, 'flail chest' can occur. According to the Association for the Advancement of Automotive Medicine's (AAAM) Abbreviated Injury Scale (AIS), it is defined as "three or more ribs fractured in more than one location (e.g. posterolateral and anterolateral) and/or resulting in paradoxical chest movements" [1].

When the rib cage is damaged and the chest movements are paradoxical, there is a high risk for injured lung parenchyma, which leads to impaired gas exchange. In patients with both injured rib cage and parenchyma contusion, the latter is the main cause of respiratory failure [2]. In addition, the injury is very painful. All these factors lead to an increased breathing workload and is a life-threatening condition [2, 3].

Treating these injuries by open reduction and internal fixation is not new; however, better implants and surgical techniques have improved the results [4]. Even operative

treatment of highly osteoporotic fractures has increased since the introduction of angular locked pre-shaped anatomical plates in titanium alloy [5]. The curved shape of the ribs are ideal for plate fixation on the convex side and good results have been proven in both the laboratory [3] as well as in clinical practice [6].

Previous studies have shown that surgical stabilisation of the injury leads to decreased respiratory restrictiveness 2 months postoperatively compared with elastic bandage and ventilator treatment [7]. One of the studies examined respiratory function 6 months after trauma and surgery, the results of which showed that surgical intervention may have had a preventive effect on both the vital capacity as well as the total lung capacity [8].

There is, however, a lack of knowledge on respiratory and physical function, mobility and pain after both conservative and stabilising surgical treatment.

The purpose of this study was to evaluate pain, respiratory function, physical function, range of motion and physical function/activity 3 and 6 months after stabilising surgery in patients with 'flail chest' due to trauma.

Patients and methods

A consecutive series of 35 patients undergoing surgery at Sahlgrenska University Hospital because of flail chest between December 2010 and March 2012 were included. Of the patients who had undergone surgery during the period, 11 were excluded because of:

Deceased, $n = 2$
Spinal cord lesion, $n = 4$
Brain injury, $n = 1$
Living too far away to participate, $n = 3$
Co-morbidity, $n = 1$

The 24 who participated (eight women) in follow-up had an average age of 55.0 years (±13.2), had a body mass index (BMI) of 25.7 (±5.0) kg/m^2, three were current smokers, ten previous smokers and three were diagnosed with lung disease [two chronic obstructive pulmonary disease (COPD) and one with sensory hyperreactivity]. Eleven of those patients included had an injury on the right side, 12 on the left and one had a bilateral injury.

The patients had 5–14 fractured ribs (median 8) and 7 of the 24 patients had a resection of pulmonary tissue. All but two patients had multiple injuries and an Injury Severity Score (ISS) of between 9–48 (median 18).

An implant based on locked screws in low profile pre-shaped titanium plates was used (Matrix®) to stabilise the fractures. This system applies the concept of angular locked plates and intramedullary nailing and has been thoroughly tested [9, 10]. Not all fractures were operated during surgery, but the flail segments were always stabilised, leaving a mechanically restored thoracic cage. A thoracotomy was performed and the pleura was cleaned, removing haematoma and debris. When required, air and blood leakage was stopped and resection of lacerated lung parenchyma performed. Two chest tubes were inserted and remained for 3–6 days.

Three and six months after surgery, the patients participated in a follow-up, where remaining pain was registered, lung volume, breathing movements, range of motion in the rib cage and thoracic spine were measured, and physical function and level of physical activity estimated.

Pain

Persisting pain (intermittent or continuous and during sleep), pain medication and what stopped or aggravated the pain were recorded. Pain during maximal breathing movements was also estimated on a 100-mm visual analogue scale [11, 12].

Spirometry

Forced vital capacity (FVC), forced expiratory volume in one second (FEV1) and peak expiratory flow (PEF) were performed in the sitting position in a standardized manner [13], according to the European Respiratory Society using an EasyOne ultrasonic spirometer (ndd Medical Technologies, Inc., Chelmsford, MA, USA). The best value of the three lowest tests was recorded.

Breathing movements

Breathing movements were tested by a respiratory movement measuring instrument, RMMI (ReMo, Inc. Keldnaholt, Reykjavik, Iceland). The apparatus consists of six laser distance sensors with an accuracy of 0.0003 mm and a measuring frequency of 21 Hz, an analogue-to-digital converter and a computer program for a PC computer. The equipment measures changes in the distances between the diodes and the surface. In the tests, the diodes were placed bilaterally, at the level of costae 3, lower part of the thorax (xiphoid process) and abdominally (lateral to the umbilicus), with a distance of approximately 1/3rd of the clavicular bone on each side of the thorax with the patient in supine [14]. Breathing movements were registered during breathing at rest (after a couple of minutes of relaxation and the patients were unaware of when the measurements were being performed) and during maximal breathing movements. The movements were registered during a period of one minute and the average movement was calculated by the computer software.

Table 1 Pain in the rib cage after trauma and surgery

	3 months ($n = 23$)	6 months ($n = 20$)
Pain		
No pain	11 (48 %)	13 (65 %)
1 day/week	3	2
2–3 days/week	1	1
4–5 days/week	2	1
6–7 days/week	6	3
Intermittent/continuous pain, *n*	11/1	2/5
Pain disturbing sleep, *n*	6	3
Pain medication, *n*	4	4
Pain during maximal breathing, *n* (mm)	1 (30 mm)	1 (50 mm)

Range of motion

Thorax excursion was assessed using a tape measure (marked in mm) around the circumference at two levels. Upper thoracic excursion was measured at the level of the 4th costae and lower thoracic excursion was measured at the level of the xiphoid process [15, 16]. The tests were performed with the patients standing with their hands placed on their head [15]. In order to be able to measure the maximal movements, instructions were given as follows; 'Breathe in maximally and make yourself as big as possible' and 'Breathe out maximally and make yourself as small as possible' [17].

Thoracic flexion was assessed by measuring the distance between skin marks at the 7th cervical spinal process and 30 cm below when the subject was standing erect and after maximal forward bending of the back and the neck [18].

Lateral flexion was measured at the level of the tip of the index finger on the thigh when standing erect and then in a maximal lateral bending position [18].

Physical function and level of physical activity

Physical function was estimated using the Disability Rating Index (DRI) questionnaire, which includes 12 items covering activities from dressing and going for walks to lifting heavy objects and exercising. The item responses were rated on visual analogue scales [19]. High values indicated impaired physical function.

The patients also estimated their physical level using a 6-point scale [20], where low values indicate a sedentary and high values an active lifestyle.

Statistics and ethical aspects

SPSS version 15.0 was used for the statistical analyses. Differences in pain estimation, physical function and activity level between the two occasions were analysed by Wilcoxon's signed-rank test. Differences in breathing movements, spirometry and range of motion were analysed by the *t*-test. Statistically significant differences were set at a p-value <0.05. The local ethics research committee approved the study and, after being given verbal information, all participants gave their informed consent before taking part in the study.

Results

Pain

The results of the frequency and persisting/intermittent pain, use of pain medication and pain during maximal breathing are presented in Table 1. The patients had significantly less pain 6 months postoperatively compared to after 3 months ($p < 0.025$). Four patients reported that they took medication (paracetamol $n = 4$, tramadol $n = 1$) regularly for the pain on both of the follow-up occasions. Activities that aggravated the pain were: working, walking downhill, lifting heavy objects, sitting, lying and sleeping supine. Activities that eased pain were: resting, changing position and walking.

Spirometry

The results of FVC, FEV1 and PEF 3 and 6 months after surgery are presented in Table 2. FVC in percent predicted

Table 2 Results of spirometry

	Predicted value (l)	3 months ($n = 23$)			6 months ($n = 20$)			Difference in percent predicted between 3 and 6 months *p*-value
		Measured value (l)	Percent of predicted (%)	*p*-value	Measured value (l)	Percent of predicted (%)	*p*-value	
Forced FVC (l)	3.80 (0.82)	3.27 (1.05)	82.8 (20.6)	0.007	3.23 (0.94)	86.4 (28.1)	0.044	0.005
FEV1 (l)	3.30 (0.75)	2.41 (0.70)	76.0 (21.4)	<0.001	2.32 (0.71)	76.9 (25.7)	0.001	0.316
PEF, (l/min)	482.6 (81.6)	373.7 (96.8)	79.0 (18.6)	<0.001	359.4 (140.5)	77.3 (27.0)	0.001	0.947

Mean (SD)

was significantly improved after 6 months compared to 3 months in those tested on both occasions ($p = 0.005$). All of the measured values of FEV, FEV_1 and PEF 3 and 6 months postoperatively were significantly lower than predicted values ($p < 0.05$).

Breathing movements

The results of the breathing movement measurements of the injured and non-injured sides are presented in Table 3. There were significant differences between the injured and non-injured sides during maximal breathing movements in the upper thoracic level at 3 ($p = 0.005$) and 6 months ($p = 0.009$). No significant differences were found between the two test occasions.

Range of motion

The range of motion in the thorax is presented in Table 4. There were no significant differences between values measured during the two occasions. After 3 months, 2/23 had a thoracic excursion reaching or exceeding reference values, 7/23 thoracic flexion, 2/23 thoracic extension and 4/23 lateral flexion. The corresponding figures after 6 months were 1/20 thorax excursion, 9/20 thoracic flexion, 1/20 thoracic extension and 9/20 lateral flexion.

Physical function and level of physical activity

The patients estimated their physical function with a median value of 26.7 mm on the DRI (range 0–49.8)

Table 3 Results of breathing movements measured by a respiratory movement measuring instrument, RMMI

	3 months		6 months		3 vs, 6 months
	Difference between injured vs. non-injured sides ($n = 23$)	p-value	Difference between injured vs. non-injured sides ($n = 20$)	p-value	p-value
Breathing movements					
Δ Upper thorax during rest (mm)	−0.90 (1.31)	0.005	−0.38 (0.65)	0.020	0.410
Δ Lower thorax during rest (mm)	−0.08 (0.79)	0.636	0.02 (0.58)	0.854	0.147
Δ Abdominally during rest (mm)	−0.39 (1.35)	0.269	0.29 (1.55)	0.429	0.259
Δ Upper thorax during maximal breathing movements (mm)	−3.24 (4.68)	0.005	1.11 (1.65)	0.009	0.207
Δ Lower thorax during maximal breathing movements (mm)	−0.09 (6.51)	0.948	1.28 (3.52)	0.131	0.955
Δ Abdominally during maximal breathing movements (mm)	−0.69 (4.22)	0.0464	−0.61 (2.52)	0.303	0.176

Mean (SD)

Δ Differences between the injured and non-injured sides

Table 4 Thoracic range of motion

	Reference value	3 months ($n = 23$)	p-value between 3 months and reference value	6 months ($n = 20$)	p-value between 6 months and reference value	p-value difference between 3 and 6 months
Thorax excursion						
Upper level (cm)	–	3.45 (1.80)	–	3.68 (1.70)	–	0.327
Lower level (cm)	5.97 (0.63)	3.67 (1.68)	<0.001	4.00 (1.71)	<0.001	0.133
Range of motion						
Thoracic flexion (cm)	2.26 (0.41)	1.80 (0.82)	0.054	2.05 (0.96)	0.352	0.251
Thoracic extension (cm)	2.66 (0.08)	0.83 (0.62)	<0.001	0.90 (0.48)	<0.001	0.270
Lateral flexion towards the injured side (cm)	17.24 (3.72)	15.43 (4.02)	0.011	15.33 (5.52)	0.207	0.114
Lateral flexion away from the injured side (cm)	17.22 (3.74)	15.64 (5.27)	0.057	15.78 (4.55)	0.192	0.164

Mean (SD)

Δ Differences between the injured and non-injured sides

3 months after the operation, which corresponds to mild to moderate disability. Six months postoperatively, the level had decreased to 16.0 mm (range 0–81.2), which corresponds to some or mild disability. The difference between the total scores 3 and 6 months after the trauma and operation was not significant ($p = 0.148$).

The patients scored their physical activity with a median value of 4 (range 2–6), i.e. "moderate exercises 1–2 h a week, e.g. jogging or swimming or light physical activities more than 4 h per week" after 3 months and with a median value of 4 (range 1–6) after 6 months ($p = 0.516$).

Discussion

The results from this study indicate that patients who had undergone stabilising surgery because of 'flail chest' have decreased range of motion and deteriorated lung function 3 and 6 months after surgery, but the reduction diminished during the follow-up period. There is a significant improvement in respiration between the two test occasions, which indicates that it takes more than 3 months for this type of trauma to heal, although, after 6 months, the patients still have significantly lower values compared to those predicted. The decrease in FVC is, however, minor, and the volume is, on average, 86 % of the predicted value, which means that the majority of the patients have results close to normal values [13]. Due to the nature of the trauma, we have no values from the patients before the surgery. It is, therefore, possible that some of the patients may have had limitations in respiration even before the injury.

There are several instruments which can measure breathing movements, such as inductive or opto-electronic plethysmography [21]. For almost a decade, the RMMI has also been used to measure and evaluate breathing movement. It is a reliable and valid instrument [22, 23] and is able to detect minor changes in movements [14]. According to the results of our follow-ups, there were no significant differences between the breathing movements on the injured side compared to the non-injured side. This indicates that the stabilisation surgery has succeeded in terms of normalising breathing movements bilaterally after major trauma to the rib cage.

The range of motion in the thorax was impaired, especially thorax excursion and extension on both test occasions. The decrease in the range of motion in flexion, extension and lateral flexion may affect the possibility to return to normal activities both at work and during leisure. In addition, the decreased thorax excursion may be one of the origins of the impaired lung volumes. For those patients who experience negativity and feel restricted by their decreased range of motion, referral to a physical therapist for individual treatment may be an option.

It is not surprising that these patients report long-term pain after the trauma they experienced. About 50 % had pain 3 months after the trauma and surgery and 35 % had pain at 6 months. They experienced both continuous and intermittent pain, but only a few patients used pain medication. It is of great importance to have regular check-ups in order to prescribe optimal medication and additional treatment to those patients who are in need.

The patients in our follow-up scored rather high physical activity levels, even though they still had deteriorated physical function. Disability was, in most patients, low, even if some patients scored high. The degree of disability is not surprising, as several patients had other injuries causing decreased possibility to walk or perform the functional movements requested in the DRI.

There are some limitations with this trial. Between the two test occasions, some of the tested variables improved. It is unknown as to whether the results given reflect the function after the healing process is ended. It is, therefore, important to perform a further follow-up when the tissues have healed after both surgery and trauma. It is also important to interpret the results with the knowledge that the group of patients is rather small and that the results are not controlled. Future trials are, therefore, needed in order to compare patients treated conservatively with those undergoing surgery.

In conclusion, patients who had undergone stabilising surgery because of 'flail chest' have decreased lung function and range of motion 3 and 6 months after surgery. Despite decreased the range of motion and remaining pain, the breathing movements were synchronic.

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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