Surg Today (2001) 31:12–17

SURGERY TODAY

Pneumatic Stabilization for Flail Chest Injury: An 11-Year Study

Hiroyuki Tanaka, Kimitaka Tajimi, Yukio Endoh, and Kunio Kobayashi

Trauma and Critical Care Center, Teikyo University School of Medicine, 11-1, Kaga 2-chome, Itabashi, Tokyo 173-8605, Japan

Abstract The use of prolonged mechanical ventilation in the treatment of flail chest injury may increase the incidence of pulmonary morbidity. The aim of this study was to examine the results of performing internal pneumatic stabilization in our hospital. A retrospective review of the medical records of 59 patients with flail chest injury who presented within an 11-year period was conducted. During the second half of the period examined, we routinely adopted three characteristic procedures in the treatment of flail chest injury, namely, pressure support on spontaneous breathing, continuous positive airway pressure via a mask, and respiratory physical therapy by physical therapists. We compared the background, prognosis, and methods of treatment for flail chest injury before and after the introduction of these three procedures. A marked decline in the duration of endotracheal intubation and controlled mechanical ventilation, and in the frequency of pulmonary morbidity, was evident following the introduction of the above procedures.

Key words Flail chest · Pneumatic stabilization · Positive pressure ventilation · Endotracheal intubation

Introduction

Flail chest injury has been treated with mechanical ventilation for more than 40 years.[1] In fact, Avery et al. coined the term "internal pneumatic stabilization" in 1956.[2] Although flail chest injury is considered to be one of the most severe conditions resulting from blunt trauma,[3] the mortality associated with this injury also depends on the degree and extent of accompanying injuries.[4] On the other hand, prolonged mechanical ventilation increases the incidence of complications,[5] such as ventilator-induced injury, major atelectasis, or hospital-acquired pneumonia,[6] among which pneumonia imparts a poor prognosis, especially in flail chest injury.[7] Therefore, the duration of mechanical ventilation in the treatment of flail chest injury must be minimized.

As a consequence of more than 40 years of treating flail chest injury by "internal pneumatic stabilization", various modes of, or adjuncts to mechanical ventilation have been disclosed. One of the many evolutions of the ventilator is the ventilatory assist mode of "pressure support", which has recently been adapted by many ventilators. Although this mode is generally named "pressure support ventilation", we believe the term "pressure support" on spontaneous breathing (PSSB) is more appropriate because the patient continues breathing spontaneously. The evolution of further treatment for this type of injury remains to be seen.

The disadvantages of mechanical ventilation have produced another conservative method of treatment for this injury. In 1975, Trinkle et al. suggested that the severity of flail chest injury may be related to associated damage caused by lung contusion.[8] They also proposed that flail chest injury should only be managed by administering appropriate analgesia through epidural catheterization and adequate oxygenation. We attempted to treat this injury according to their method; however, as a number of patients showed progressive respiratory distress, we began to use continuous positive airway pressure (CPAP) without endotracheal intubation (ETI), but through a face mask fitted on the face of the patient who is breathing spontaneously (mask-CPAP). In our hospital, physical therapists have periodically begun to perform formal respiratory physical therapy (RPT), mainly utilizing a procedure called "squeezing," exerting hand pressure on the chest wall just above the

Reprints requests to: H. Tanaka, Department of Emergency Medicine, Akita University School of Medicine, 1-1-1 Hondoh, Akita City, Akita 010-8543, Japan
Received: July 5, 1999 / Accepted: July 25, 2000

damaged segment of the lung.[9] We have treated the injury exercising our ingenuity as mentioned above.

In the present study, we retrospectively investigated 59 consecutive patients admitted to our hospital with flail chest injury within an 11-year period. We examined the background and prognosis of the patients and compared the treatment for flail chest injury before and after the introduction of the three procedures, namely, PSSB, CPAP, and RPT. The aim of this study was to examine the results of "internal pneumatic stabilization" in our hospital.

Methods

A retrospective review was conducted of the records of all patients admitted to our hospital with blunt trauma injuries between January 1985 and December 1995, excluding those with no vital signs on admission. From these admissions, we analyzed patients with rib fractures who were clinically diagnosed with a flail chest injury. The diagnosis was based on the presence of a flail segment, determined by paradoxical motion of the chest wall. Patients with a flail chest injury caused by cardiopulmonary resuscitation were excluded. The following information was collected: age, gender, associated injuries, prognosis, and cause of death. Also calculated was the incidence of flail chest among all cases of trauma, among all chest injuries, and among all chest injuries with rib fractures. As the aim of the study was to investigate "internal pneumatic stabilization" as a method of treatment for flail chest injury, we examined only the traumatized patients who survived.

The mechanism of the external force or the symptoms of respiratory distress principally alert us to the possible existence of a flail chest injury. Clinical evidence of respiratory distress is comprehensively inferred by the vital signs, the pattern of chest wall movement on spontaneous breathing, the level of consciousness, the monitoring of oxygen saturation percutaneously, blood gas analysis, and urinary output, all of which should be monitored for as long as possible during hospitalization.

In our hospital, September 1989 was considered to be a turning point in the treatment for flail chest injury as this was when the above three procedures were initiated. We divided the examination period into two groups: from January 1985 to August 1989 (group A) and from September 1989 to December 1995 (group B). The following information was collected: age, gender, history of thoracotomy, Injury Severity Score (ISS), number of rib fractures, oxygenation index on admission, and pulmonary morbidity. The ISS was calculated according to the method of Baker and O'Neil.[10] Only rib fractures demonstrated by a plain chest X-ray were included. The oxygenation index was calculated as arterial oxygen tension (PaO_2, mmHg) divided by the fractional concentration of oxygen in the inspired gas (FiO_2). Pulmonary morbidity consisted of major atelectasis and hospital-acquired pneumonia. Major atelectasis was defined as that extending over one lobe or more of the lung radiographically, and pneumonia was defined as the positive culture of phlegm in addition to clinical signs such as spiking fevers, a large volume of phlegm, leukocytosis, and the acceleration of acute inflammatory reactions.

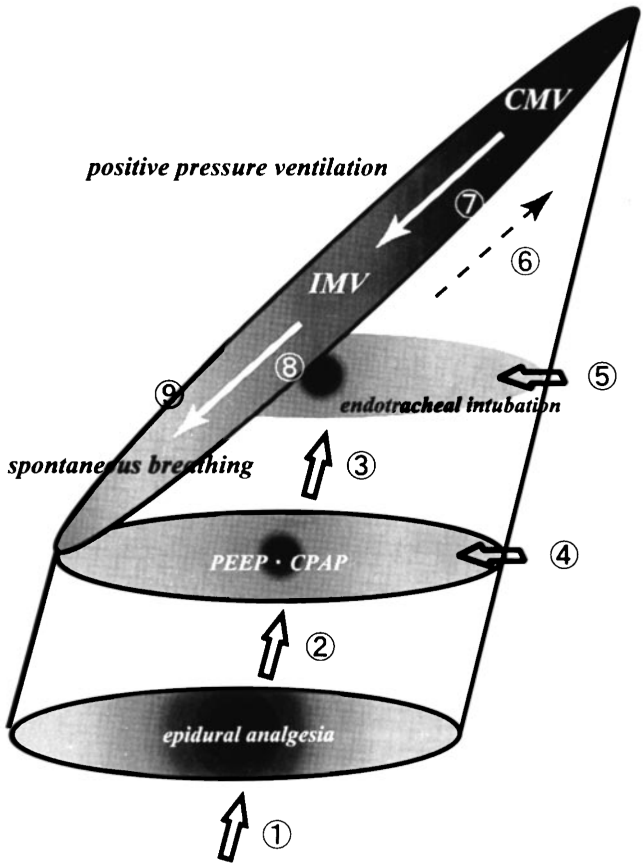

Fig. 1. Protocol for the treatment of patients with flail chest injury. *CMV*, controlled mechanical ventilation or continuous mandatory ventilation; *IMV*, (synchronized) intermittent mandatory ventilation; *PEEP*, positive end-expiratory pressure; *CPAP*, continuous positive airway pressure

When patients were breathing spontaneously on admission and stability of vital signs and breathing pattern was maintained under oxygen therapy, we performed an epidural catheterization immediately following the initial diagnosis (Fig. 1, ①). Thereafter, if clinical evidence of respiratory distress existed, we initiated CPAP using a mask fitted on the patient's face as a first step (Fig. 1, ②). When symptoms or signs of respiratory distress continued or progressed following CPAP, ETI was performed as a second step (Fig. 1, ③). This decision complied with the principles to avoid ETI and maintain spontaneous breathing; however, we sometimes performed the procedure following CPAP without ETI (Fig. 1, ④), depending upon the degree of respiratory distress. Other patients required ETI immediately on admission (Fig. 1, ⑤) due to severe respiratory distress, emergency surgery following admission, or an abrupt change in their condition. They often needed mandatory ventilation (Fig. 1, ⑥) and an epidural catheterization was performed whenever possible for such patients.

When patients required ETI and mandatory ventilation as shown in the top part of Fig. 1, they were weaned off ventilatory support (Fig. 1, ⑦). This process of weaning off ventilatory support and ETI proceeded while monitoring for any clinical evidence of respiratory distress. If the weaning process was unsuccessful, mandatory ventilation was continued using muscle relaxants if needed, or another ventilatory support system, such as differential lung ventilation or pressure-controlled ventilation, was considered.

The weaning process commenced with the change to intermittent mandatory ventilation (IMV), then the rate of mandatory ventilation was decreased (Fig. 1, ⑧). When patients began breathing spontaneously, by pressure support on spontaneous breathing (PSSB) only, we monitored the tidal volume and for any signs of respiratory distress. When the patient's tidal volume was restored, we gradually reduced support pressure as the next step. The adoption of PSSB allowed for easy weaning from mandatory ventilation. When support pressure was completed, which was not necessary at zero, the patient was extubated as soon as possible (Fig. 1, ⑨). Following extubation, patients were fitted with a CPAP mask if needed. We considered endotracheal reintubation or surgical fixation again when the patient did not cough up enough phlegm, even without symptoms or signs of respiratory distress.

To compare the methods of conservative treatment for flail chest injury before and after the turning point, we examined the incidence and duration of the following procedures: epidural catheterization and analgesia, RPT, ETI, continuous positive airway pressure and/or positive end-expiratory pressure (CPAP/PEEP), PSSB, synchronized intermittent mandatory ventilation (SIMV), and controlled mechanical ventilation, in the form of continuous mandatory ventilation (CMV). ETI was defined as intubation through the trachea or tracheotomy with a cuffed tube. In the present study, patients breathing spontaneously through a metal (noncuffed) tracheotomy tube were considered not to have ETI.

All calculations for statistical analyses were performed by Statview computer software (Adacus Concepts, Berkeley, CA, USA). All values are expressed as mean ± SD. Statistical analyses were based on the *F*-test. Significance between the groups was determined by the unpaired *t*-test only when a significant difference was found by the *F*-test. Incidence parameters were analyzed by Fisher's exact probability test. A confidence level of 95% or higher was considered significant.

Results

A total of 59 patients with flail chest injury caused by blunt trauma were admitted to our hospital during the study period, which corresponded to 1.9% of all 3165 patients admitted for trauma injuries, 6.3% of 941 patients with chest injuries, and 10.4% of 568 patients with rib fractures. The 59 patients ranged in age from 14 to 82 years. The patients with flail chest injury had suffered various degrees of external force to different areas of the chest. The present study demonstrated that almost all patients with flail chest injury had associated injuries, some of which had easily induced massive hemorrhage, including damage to the liver in 12 patients, the spleen in 7, the kidney in 7, the pelvis in 13, and fractures of the extremities (AIS $\geqq 2$) in 18. Some patients suffered an external blow to the cranium, resulting in skull and facial fractures in 6 and 9 patients, respectively, as well as severe brain damage from intracranial hemorrhage or hematoma in 14 patients, and cerebral contusion in 7 patients.

We divided the 59 patients into two groups according to the introduction of the three procedures (Table 1). Thus, group A was comprised of 39 patients treated between January 1985 and August 1989, and group B was comprised of 20 patients treated between September 1989 and December 1995. Of these 59 patients, 25 (43%) died, 20 of whom were in group A, demonstrating a mortality rate of 51% (20/39), and 5 of whom were in group B, demonstrating a mortality rate of 25% (5/20). The mortality rate was lower in the latter period, but without statistical significance. Massive hemorrhage with hemorrhagic shock and severe brain damage were the two major causes of death in this series. Of the 25 patients with flail chest injury who died, 15 died within 3 h of the accident due to massive hemorrhage. Another 6 died within a mean period of 3 days after the accident due to severe brain damage. The remaining 4 patients died as a result of hospital-acquired pneumonia or sepsis, being infection-related deaths. Of the total 59 patients with flail chest injury, 34 survived during the period examined; 19 in the former period and 15 in the latter period. Thoracotomy was performed to repair the lung, the bronchus, or the pericardium, on the day of admission or the following day in 6 of these 34 patients. The surviving patients in both groups were almost

Table 1. Comparison of backgrounds, prognoses, and other factors between the groups

	Group A (1985–1989)	Group B (1989–1995)	*P* value
Number of patients with flail chest	39	20	
age (years, mean ± SD)	46 ± 17[a]	46 ± 12	0.2685
sex (male/female)	29/10	16/4	0.6297
Number of deaths	20	5	
Mortality rate (%)	51	25	0.0531
Number of patients who survived	19	15	
age (mean ± SD)	44 ± 17[b]	41 ± 10	0.3088
sex (male/female)	16/3	11/4	0.4361
Injury Severity Score	31 ± 12	32 ± 9	0.3718
rib fractures (mean ± SD)	7 ± 5	7 ± 3	0.4756
oxygenation index	219 ± 80	198 ± 76	0.7785
Pulmonary morbidity			
major atelectasis (%)	18 (95)	7 (47)	0.0016*
hospital-acquired pneumonia (%)	16 (70)	4 (27)	0.0023*
Number of patients who underwent thoracotomy (%)	5 (22)	1 (9)	0.8409

Group A was composed of patients admitted with flail chest injury before the turning point in our hospital (between January 1985 and August 1989), and Group B was composed of those admitted after the turning point (between September 1989 and December 1995)
* Statistically significant differences were found
[a] Excluded patients of unknown age, $n = 38$
[b] Excluded patients of unknown age, $n = 18$

Table 2. Incidence and duration of each maneuver of pneumatic stabilization

	Incidence			Duration		
	Group A	Group B	*P* value	Group A	Group B	*P* value
Epidural analgesia	8	10	0.1542	—	—	
RPT	0	10	0.0017*	—	—	
CPAP/PEEP	11	14	0.0200*	170 ± 148	132 ± 116	0.6265
ETI	13	11	0.7549	431 ± 297	121 ± 88	0.0060*
PSSB	0	11	<0.0001*	—	100 ± 76	—
IMV	12	11	0.5289	87 ± 91	60 ± 56	0.5276
CMV	14	7	0.1075	135 ± 127	26 ± 21	0.0048*

Group A was composed of 19 patients admitted between January 1985 and August 1989, and group B was composed of 15 patients admitted between September 1989 and December 1995
RPT, respiratory physical therapy performed by physical therapists: CPAP/PEEP, continuous positive airway pressure and/or positive end-expiratory pressure; ETI, endotracheal intubation; PSSB, pressure support on spontaneous breathing; IMV, intermittent mandatory ventilation; CMV, controlled mechanical ventilation
* Statistically significant differences were found

identical with respect to mean age, gender, and the ISS (Table 1); however, a statistically significant difference in the incidence of pulmonary morbidity, including major atelectasis and pneumonia, was seen between the two groups (Table 1).

The incidence at which different procedures were performed for the treatment of flail chest injury and their duration is shown in Table 2. Following the introduction of the three procedures, the incidences of epidural catheterization, CPAP/PEEP, PSSB, and SIMV increased, while that of CMV decreased. There was a statistically significant difference between the groups only in the incidence of CPAP/PEEP, although the incidence of RPT and PSSB naturally differed. The incidence of ETI was identical in the former and latter periods. It was notable that the duration of ETI, CPAP/PEEP, SIMV, and CMV decreased following the introduction of the three procedures; however, there was a statistically significant difference only in ETI and CMV between the groups.

Discussion

The two methods used for the treatment of flail chest injury are "internal pneumatic stabilization" and surgical fixation. In Europe, a number of studies have shown significant improvement following the placement of a fixture device.[11] In fact, surgeons favor surgical fixation over pneumatic stabilization because there are fewer ventilator-associated complications.[12] As prolonged mechanical ventilation has a detrimental effect on the prognosis of the patients,[13] its duration and that of ETI must be minimized in the treatment of flail chest injury. Trunkey argued that the rationale for surgical fixation is to minimize the duration of mechanical ventilation by initiating "internal pneumatic stabilization" if the chest wall injury is the primary indication for ventilatory assistence.[14] Nevertheless, there exists no precise opinion on the indications for surgical fixation and some textbooks suggest that it is basically negative.[15] Accordingly, we would never routinely adopt surgical fixation, but rather we have endeavored to surmount the disadvantages of "internal pneumatic stabilization."

Since the introduction of positive pressure ventilation for treating flail chest injury by "internal pneumatic stabilization," ventilators have made remarkable progress in terms of treatment. Cullen et al. recommended IMV as a useful method for pneumatic stabilization in the treatment of flail chest injury.[16] Their recommendation demonstrates that "internal pneumatic stabilization" may not always mean the original intermittent positive pressure ventilation. PSSB as a method of ventilatory support is pressure- or flow-initiated, pressure-limited, and a flow-cycled ventilatory assist mode using a high-flow gas supply system that can be applied when the tidal volume of spontaneous breathing is too low. PSSB was used for 11 of the 15 patients in group B of this study (Table 2). Once of the advantages of using PSSB is that it may allow the patient to be weaned from the ventilator earlier than when SIMV alone is used. We consider that earlier weaning from the ventilator enabled earlier extubation. As PSSB produces positive pleural pressure and minimal load to the flail segment, this procedure may also be useful for the treatment of flail chest injury. We suspected that the application of PSSB contributed to the decreased incidence and duration of mandatory ventilatory assistance, such as SIMV or CMV, as shown by the significantly reduced duration of CMV in group B (Table 2).

On the other hand, Tzelepis et al. investigated chest wall distortion in patients with flail chest injury according to different various ventilator modes, namely, CMV, IMV, and CPAP.[17] They reported that the degree of chest wall distortion during spontaneous breathing alone under CPAP was less than that during IMV. It was also shown that CPAP using a high gas flow system of 80–100 l/min resulted in the least distortion, which was possibly related to the positive pleural pressure and minimal load due to the high gas flow system. This suggests that CPAP plays a more effective role in pneumatic stabilization when used to treat flail chest injury than any other positive pressure ventilation. In other words, CPAP may provide enough pneumatic force to stabilize the flail segment and the mechanism may be valid for the mask-CPAP system. Therefore, we consider that CPAP provides genuine "internal pneumatic stabilization," simply because the utilization of PSSB and/or CPAP means preservation of spontaneous breathing. In accordance with the above-mentioned proposal by Trinkle et al.,[8] we endeavored to avoid using ETI and mechanical ventilation during the initial period of this study. As it was difficult for patients with respiratory distress on admission to lie in a lateral position, hunch up, and remain motionless during the procedure of epidural catheterization, whenever possible we initiated mask-CPAP, even before catheterization. Of the 15 surviving patients in group B, 3 were managed with mask-CPAP, whereby ETI was able to be avoided (Table 2). Thus, it stands to reason that PSSB and mask-CPAP should be promoted in an effort to decrease the incidence and duration of ETI, and that of positive pressure ventilation.

The mortality associated with flail chest injury depends mainly on the degree and extent of the other injuries.[4] Accordingly, in the present study, patients who had suffered multiple trauma accounted for the majority of the nonsurvivors, fatal hemorrhagic shock and severe brain damage being the two major causes of death in patients with flail chest injury, accounting for 21 of the 25 deaths (84%). The other four deaths were attributed to hospital-acquired pneumonia or sepsis, being infection-related deaths, which may be preventable in patients with flail chest injury. This result suggests that the mortality of patients with flail chest injury may depend on the prevention of infectious complications, especially in those without major associated injuries. In other words, the ultimate aim of treatment for flail chest injury could be to eliminate the risk of death due to infection. Consequently, it is important to prevent infection and avoid infection-promoting factors. Pneumonia is the most common infection in patients with flail chest injury and bronchial hygiene is an important factor in the prevention of pneumonia. Adequate bronchial hygiene therefore promotes a better prognosis for these patients.

As bronchial hygiene is difficult to maintain in patients during ETI and/or mechanical ventilation, the complete avoidance of ETI or extubating as early as possible is important. Furthermore, a shortened duration of mechanical ventilation and/or preservation of spontaneous breathing will promote better bronchial hygiene. Other distinctive factors for improving outcome may be prudent intubation, early extubation, or the preservation of spontaneous breathing. RPT, which is performed in our hospital, is considered an active, not passive, method, and its appropriate enforcement has a positive effect on bronchial hygiene. Epidural analgesia allows such patients to undergo RPT for bronchial hygiene. Moreover, the initiation of RPT and the presence of physical therapists in the intensive care unit promote the staff to recognize the importance of observing bronchial hygiene when carrying out procedures. From the present study, we presume that proper bronchial hygiene contributed to better pulmonary morbidity, which may induce a better prognosis in patients treated for flail chest injury (Table 2).

Through our experience of treating flail chest injury, the following guidelines have been established:

1. Epidural catheterization must be initially performed for the administration of localized analgesia
2. The flail segment must be pneumatically stabilized when the patient is in respiratory distress
3. ETI should be avoided and spontaneous breathing preserved if possible
4. Respiratory physical therapy should be initiated as soon as possible following pain control

Investigating these guidelines thoroughly, the treatment of flail chest injury must involve prompt and continuous bronchial hygiene. Therefore, we designed a protocol for the treatment of patients with flail chest injury as outlined in Fig. 1. It remains unclear whether or not better bronchial hygiene directly limits the need for prolonged ETI and controlled mechanical ventilation. Moreover, there is no evidence that the induction of bronchial hygeine reduces pulmonary morbidity. Nevertheless, we believe that our protocol can limit the duration of positive pressure ventilation, and even the extent of treatment required, if it is applied strictly and appropriately. A shorter duration of treatment for flail chest injury when applying this protocol would minimize the disadvantages of "internal pneumatic stabilization." Furthermore, according to our protocol, some patients previously considered as candidates for surgical fixation due to apprehension from prolonged mechanical ventilation can avoid surgery. In conclusion, further studies will be necessary to establish the importance of this protocol in the treatment of flail chest injury.

References

1. Rodriguez A (1990) Injuries of the chest wall, the lung and the pleura. In: Turney SZ, Rodriguez A, Cowley RA (eds) Management of cardiothoracic trauma. Williams and Wilkins, Baltimore, pp 155–177
2. Avery EE, Morch ET, Benson DW (1956) Critically crushed chest: a new method of treatment with continuous mechanical hyperventilation to produce alkalotic apnea and internal pneumatic stabilization. J Thorac Cardiovasc Surg 32:291–311
3. Committee on Trauma (1989) Advanced trauma life support instructor manual. American College of Surgeons, Chicago
4. Ciraulo LL, Elliot D, Mitchell KA, Rodriguez A (1994) Flail chest as a marker for significant injuries. J Am Coll Surg 178:466–470
5. Paris F, Terrazona V, Garcia-Zarza A (1991) Controversial aspects of surgical fixation for traumatic flail chest. In: International trends of general thoracic surgery, vol. 7, Surgical management of chest injuries. Saunders, Philadelphia, pp 306–309
6. Cross AS, Roupe B (1981) Role of respiratory assistance device in endemic nasocomial pneumonia. Am J Med 70:681–685
7. Craven DE, Lunches LM, Kilinsky V (1986) Risk factors for pneumonia and fatality in patients receiving continuous mechanical ventilation. Am Rev Respir Dis 133:792–796
8. Trinkle JK, Richardson JD, Franz JL, Gover FL, Arom KV, Holmstrom FMG (1975) Management of flail chest without mechanical ventilation. Ann Thorac Surg 19:355–365
9. Ciesla ND (1996) Chest physical therapy for patients in the intensive care unit. Phys Ther 76:609–624
10. Baker S, O'Neil B (1976) The injury severity score: an update. J Trauma 16:882–885
11. Gaillard J, Dahan M (1987) The injured chest wall; operative stabilization. In: International trends of general thoracic surgery, vol. 2, Major challenge. Saunders, Philadelphia, pp 258–281
12. Thomas AN, Blaisdell FW, Lewis FR Jr, Schlobohm RM (1978) Operative stabilization for flail chest after blunt trauma. J Thorac Cardiovasc Surg 75:793–801
13. Freedland M, Wilson RF, Bender JS, Levison MA (1990) The management of flail chest injury, factors affecting outcome. J Trauma 30:1460–1468
14. Trunkey DD (1994) Chest wall injuries. In: Blaisdell FW, Trunkey DD (eds) Trauma management: cervicothoracic trauma, vol. 3, 2nd edn. Thieme, New York, pp 190–214
15. Cogbill TH, Landercasper J (1996) Injury to the chest wall. In: Feliciano DV, Moore FE, Mattox KL (eds) Trauma, 3rd edn. Appleton & Lange, Connecticut, pp 355–373
16. Cullen P, Modell JH, Dirby RR, Klein EF, Long W (1975) Treatment of flail chest. Use of intermittent mandatory ventilation and positive end-expiratory pressure. Arch Surg 110:1099–1103
17. Tzelepis GE, Mccool FD, Hoppin FG Jr (1989) Chest wall distortion in patients with flail chest. Am Rev Respir Dis 140:31–37