Treatment with Internal Pneumatic Stabilization for Anterior Flail Chest

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Objective: Advantages and disadvantages have been reported for both internal pneumatic stabilization and surgical stabilization as treatments for anterior flail chest. We retrospectively investigated therapeutic outcomes and problems associated with pneumatic stabilization for anterior flail chest patients.
Methods: Subjects were 43 patients admitted to Tokai University Hospital with anterior flail chest, 1988-1999. Pneumatic stabilization was performed with continuous positive pressure ventilation and a positive end-expiratory pressure of 10 cm H_20 or higher. We analyzed mean times required for pneumatic stabilization, weaning, and mechanical ventilation; sternal fracture (presence vs. absence); survival, and other clinical variables.
Results: Continuous positive pressure ventilation was needed for 12.5 days and mechanical ventilation for 15.6 days. Flail chest was relieved by pneumatic stabilization alone in 42 patients; 1 patient with a displaced sternal fracture required sternal fixation. Four cases were complicated by pneumonia. Pneumatic stabilization allowed physicians to treat severe combined nonthoracic organ injuries during the acute phase. Forty patients survived, and 3 died from nonthoracic injuries (survival rate 93%).
Conclusions: Anterior flail chest unaccompanied by sternal fracture can be relieved by pneumatic stabilization alone. We hope to combine pneumatic stabilization with simple surgical stabilization in anterior flail chest patients to shorten the mechanical ventilation period.

Key words: Blunt chest trauma, Chest wall trauma, Flail chest, Internal pneumatic stabilization, Surgical stabilization

INTRODUCTION

Advantages and disadvantages have been reported for both internal pneumatic stabilization and surgical stabilization as treatments for anterior flail chest [1]. Pneumatic stabilization is often avoided because it requires long-term mechanical ventilation and may be complicated by pneumonia owing to long-term administration of sedatives [2]. Conventional surgical stabilization methods do not have these drawbacks, but they inflict a great deal of surgical stress as well as trauma damage. The treatment of flail chest continues to develop: Actis Dato *et al*. [3] reported simple surgical stabilization by means of a new device, and Tanaka *et al*. [4] reported a method involving use of continuous positive airway pressure (CPAP) through a face mask.

Since 1988, we have consistently performed pneumatic stabilization in anterior flail chest patients unless they have undergone posterolateral thoracotomy. The therapeutic outcomes of pneumatic stabilization and problems associated with it were investigated in this retrospective study.

MATERIAL AND METHODS

During the 12-year period 1988-1999, 550 individuals with blunt chest trauma were admitted to the Emergency Critical Care Center of Tokai University Hospital. Of these 550 patients, 90 (16%) had at least 3 ribs broken in 2 or more places. These were 51 patients with anterior flail chest and 39 with posterior or lateral flail chest. The patients with posterior or lateral flail chest were desensitized by continuous epidural anesthesia, given respiratory physiotherapy by mask CPAP, and placed in a supine position against a rigid mattress without tracheal intubation. Anterior flail chest was diagnosed by gross examination upon patients' arrival at the Emergency Critical Care Center. Eight patients underwent posterolateral thoracotomy for massive hemothorax and bronchial injury within 12 hours after arrival [5, 6]. Internal pneumatic stabilization was initiated upon admission in the remaining 43 patients.

Patients treated by pneumatic stabilization comprised 26 men and 17 women and included 1 teenager, 3 patients in their 20s, 4 in their 30s, 7 in their 40s, 11 in their 50s, 14 in their 60s, and 3 in their 70s. Mean age in this group was 53 ± 15 (means ± standard deviation) years. Thirty of these patients sustained their injuries in traffic accidents, 8 in falls, 2 by being gored by cattle, and 3 in work-related accidents.

Pneumatic stabilization included continuous positive pressure ventilation (CPPV) with positive end-expiratory pressure (PEEP) of 10 cm H_2O or higher. Decisions about termination of pneumatic stabilization were made approximately 7 days after admission when thoracic wall extension and improvement in pulmo-

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Table 1 Combined injuries in anterior flail chest patients and treatment of these injuries within 24 hours after arrival

	Treatment	Nomber of patients
Thoracic injury		
Intrabronchial hemorrhage	Bronchial block with a Univent	6
Aortic arch injury	Hypotensive therapy	1
Hemothorax		
Intercostal vessels	Hemostasis (VATS)	2
Pulmonary laceration	Pulmonary lobectomy	6* **
Diaphragmatic rupture	Diaphragmatic reconstruction	1*
Bronchial injury	Suture repair	1*
Nonthoracic organ injury		
Head injury	Ventricular drainage	3
Abdominal injury		
Stomach and spleen rupture	Gastrectomy and splenectomy	2
Diaphragmatic rupture	Diaphragmatic reconstruction	1
Extremity injury		
Open fracture of the femur	D+ESF of the femur	1†
Open fracture of the leg	D+ESF of the leg	2
Blood vessel injury		
SCA injury	TAE of the SCA	1
Spleen and liver injuries	TAE of the SA and HA	1
Comminuted fracture of a lumbar vertebra	TAE of the LA	1
Pelvic fracture	TAE of the IIA	3

* Patients with posterolateral thoracotomy excluded from the assessment of pneumatic stabilization because the ribs were fixed during posterolateral thoracotomy.
** Four of these patients died of hemorrhagic shock during surgery.
† One patient died of sepsis resulting from infection of the femoal fracture
D+ESF: debridement and external skeletal fixation; HA: hepatic artery; SCA: subclavian artery;
TAE: transcatheter arterial embolization; VATS: video-assisted thoracoscopic surgery

nary contusion were identified on chest radiographs. Synchronized intermittent mandatory ventilation (SIMV), pressure support ventilation (PSV), and/or CPAP was used to wean patients from CPPV. If the flail segment persisted upon gross examination, patients continued on CPPV and were evaluated again by the same procedure 2-4 days after the first evaluation. During the period of CPPV, anesthesia was achieved by continuous drip infusion of morphine hydrochloride (0.1-0.4 mg/kg/h) and vecuronium bromide (0.05-0.1 mg/kg/h).

Thoracic helical computed tomography (CT) was performed in all 43 anterior flail chest patients within 6 hours after arrival. This was done to identify pulmonary contusion, injury to any of the thoracic great vessels, or bronchial injury. Because costal cartilage and rib fractures in patients with anterior flail chest could not be identified on plain chest radiographs or helical CT images obtained in the horizontal plane, it was difficult to accurately determine the number of fractures.

We examined the times required for pneumatic stabilization (CPPV), weaning, and mechanical ventilation in relation to sex, age (<50 years vs. ≥50 years), sternal fracture (presence vs. absence), head abbreviated injury scale (AIS^{90}) score, and injury severity score (ISS^{90}). Differences were analyzed statistically by x^2 test. A p value of < 0.05 was considered statistically significant. Values are mean ± SD.

RESULTS

All 43 patients had an underlying moderate or severe pulmonary contusion. The AIS^{90} score for thoracic injury was 4 in 33 patients and 5 in 10 patients. Eleven of the 43 patients were in shock, with systolic blood pressure of less than 80 mm Hg upon arrival. Seventeen of the 43 patients were hypoxemic, with PaO_2 of less than 60 mm Hg upon arrival despite 10 L oxygen inhalation therapy. Chest tubes were inserted with water-sealed drainage in all 43 patients. The volume of blood drained from the chest tube during the first 24 hours was 500 ml or more in 15 patients. In 2 patients with disrupted intercostal vessels and blood volume in excess of 1,500 ml, hemostasis was achieved by video-assisted thoracoscopic surgery (Table 1). Flail chest was associated with massive endobronchial bleeding in 6 patients. These patients were treated for 24 hours by bronchial occlusion with a Univent (Fuji Systems Corporation, Tokyo, Japan) with a built-in endobronchial blocker [7].

Nonthoracic organ injuries given an AIS^{90} score of 3-5 were of the head in 16 patients (37%), the abdomen in 9 (21%), and the pelvis or extremities in 11 (26%). The ISS^{90} was noted as 16-25 in 16 patients, 26-50 in 24, and 51-59 in 3. Nine patients underwent surgery on nonthoracic organs within 24 hours after arrival (Table 1). Six patients underwent transcatheter arterial embolization within 4 hours after arrival. These surgical procedures were performed under CPPV.

A thoracic surgeon explained the medical condition to each flail chest patient whose consciousness level was clear, whose respiratory condition was comparatively stable, and who was not in shock. The thoracic surgeon then performed tracheal intubation and start-

Table 2 Periods of CPPV and mechanical ventilation per clinical factors

		CPPV period (days)	Weaning period (days)	MV period (days)	Number of patients
Overall		12.5 ± 4.1	3.1 ± 2.9	15.6 ± 5.4	n = 43
Sex	male	12.8 ± 4.4	3.1 ± 2.9	15.7 ± 6.0	n = 26
	female	12.1 ± 3.7	3.4 ± 3.1	15.5 ± 4.6	n = 17
Age	< 50 years	11.5 ± 3.8	3.5 ± 3.1	14.9 ± 4.6	n = 15
	≥ 50 years	13.1 ± 4.3	2.9 ± 2.8	16.0 ± 5.9	n = 18
Sternal fracture	absent	12.7 ± 3.9	2.9 ± 2.7	15.1 ± 5.2	n = 38
	present	15.4 ± 4.2	4.4 ± 3.8	19.8 ± 5.7	n = 5
Head AIS[90] score	0-2	12.5 ± 4.5	2.0 ± 1.9 *	14.6 ± 5.4	n = 27
	3-5	12.6 ± 3.6	4.8 ± 3.4	17.4 ± 5.1	n = 16
ISS[90]	16-25	12.3 ± 5.0	2.6 ± 2.7	14.9 ± 7.0	n = 16
	26-59	12.7 ± 3.6	3.3 ± 2.9	16.0 ± 4.3	n = 27

Data are expressed as means ± standard deviation.
*$p < 0.01$
Weaning period = SIMV + PSV + CPAP period; MV period = CPPV period + weaning period
AIS[90]: abbreviated injury scale[90]; CPAP: continuous positive airway pressure;
CPPV: continuous positive pressure ventilation; IPS: internal pneumatic stabilization;
ISS[90]: injury severity score[90]; MV: mechanical ventilation; PSV: pressure support ventilation;
SIMV: synchronized intermittent mandatory ventilation

ed mechanical ventilation with anesthesia. However, when flail chest was accompanied by respiratory insufficiency, shock, or disturbed consciousness, the thoracic surgeon's primary focus was tracheal intubation and mechanical ventilation, which were performed without obtaining the patient's consent. After removal of the tracheal tube, the attending surgeon explained the medical procedures to the patient.

Flail chest was relieved by pneumatic stabilization alone in 42 of the 43 patients. In the remaining patient, the distal end of a transverse fracture of the corpus sterni led to anterior displacement, the fracture site became pseudoarthrotic, and the flail segment persisted. Flail chest improved immediately when sternal surgical fixation was performed on hospital day 22.

In the 43 patients who underwent pneumatic stabilization, the mean duration of CPPV was 12.5 ± 4.1 days, the mean weaning period (SIMV + PSV + CPAP) was 3.1 ± 2.9 days, and the mean mechanical ventilation period (CPPV + weaning) was 15.6 ± 5.4 days (Table 2). The CPPV, weaning, and mechanical ventilation periods did not differ in length between the sexes. Neither did they differ between patients aged 50 years or more (n = 28) and those aged 49 years or less (n = 15). The CPPV, weaning, and mechanical ventilation periods were longer in patients with sternal fracture (n = 5) than in patients without sternal fracture (n = 38). Because there were only 5 patients with sternal fracture, there were no statistical differences in the CPPV, weaning, and mechanical ventilation periods between patients with and without sternal fracture.

Mean CPPV duration was 12.6 ± 3.6 days, mean weaning period was 4.8 ± 3.4 days, and mean mechanical ventilation period was 17.4 ± 5.1 days for patients with a head AIS[90] score of 3-5 (n = 16). The corresponding periods were 12.5 ± 4.5, 2.0 ± 1.9, and 14.6 ± 5.4 days for patients with a head AIS[90] score of 0-2. The weaning period for patients with head injury was significantly longer than that for patients without head injury ($p < 0.01$).

Thirty-two patients underwent tracheotomy, and 11 did not. The 32 patients who underwent tracheotomy included 16 with a head AIS[90] score of 3-5. All 32 patients required mechanical ventilation for 12 days or more. Jaundice resulting from a total bilirubin level of more than 3.0 mg/dl was observed in 22 patients. The bilirubinemia developed 5-10 days after the start of CPPV. It was determined that cholestatic jaundice had been induced by drugs, such as sedatives, administered intravenously. The total bilirubin level in these patients returned to less than 3.0 mg/dl within 7 days after the sedatives were eliminated.

Pneumonia was associated with mechanical ventilation in 4 patients, but it responded to antibiotics. The 4 patients in whom pneumonia developed were treated before 1994 and had chronic obstructive pulmonary disease. The lives of 40 patients were saved; the other 3 patients died. One patient died of brain injury within 30 days of arrival, and 2 patients died of nonthoracic organ injury after 30 days. Flail chest was managed by pneumatic stabilization in all 3 of these patients. Of the 40 surviving patients, 18 without brain or extremity injuries returned to their daily work or school routine within 4 months after injury.

DISCUSSION

Multiple anterior rib fractures differ pathophysiologically from multiple posterior or lateral rib fractures. Flail chest rarely develops from the posterior or lateral type because the scapulae and thoracic vertebrae help support the fractured ribs. Anterior fractures often lead to flail chest because there is no bone to compensate for the fractured ribs. Bilateral anterior flail chest with sternal fracture is particularly serious. We used continuous epidural anesthesia [8], mask-CPAP [4], pulmonary physiotherapy, and supine positioning against a rigid mattress to treat patients with posterior or lateral flail chest. Anterior flail chest was identified in our study patients by gross examination upon arrival, and early initiation of CPPV was required because of respiratory failure due to pulmonary contusion. In many of these patients, flail chest was associated with acute circulatory failure, shock, and severe nonthoracic organ injuries.

Avery *et al.* [9] in 1956 were the first to report treating flail chest with mechanical ventilation, and in 1978, Thomas *et al.* [10] reported on treatment by surgical stabilization. Since the Thomas *et al.* report, surgical treatment has been preferred, and there have been many reports on surgical stabilization. In 1997, Mouton *et al.* [11] performed surgical stabilization with a 3.5-mm-thick reconstruction plate, and surgical stabilization methods have continued to improve. In 1990, Freedland *et al.* [2] reported that pneumatic stabilization induced complications such as pneumonia, atelectasis, adult respiratory distress syndrome, and sepsis in 47% of flail chest patients, with a consequent mortality rate of 11%. Since then, surgeons have rarely chosen pneumatic stabilization as treatment for flail chest. In 1999, Actis Dato *et al.* [3] reported a revolution in surgical pneumatic stabilization fostered by development of new devices. In 2001, Tanaka *et al.* [4] reported the results of mask-CPAP therapy, and changes in the pneumatic stabilization technique began to emerge. Most studies have reported a better therapeutic outcome with surgical stabilization than with pneumatic stabilization, probably because of differences in patients' conditions.

We believe that surgical stabilization was usually selected for patients who were in generally stable condition with mild nonthoracic organ injuries, whereas pneumatic stabilization was usually selected for patients in unstable condition with multiple organ injuries associated with brain damage. We have consistently treated patients with anterior flail chest by pneumatic stabilization, with the exception of those requiring posterolateral thoracotomy for massive hemothorax or bronchial injury [5, 6]. Flail chest resolved in response to pneumatic stabilization alone in 42 of our 43 patients. In the remaining patient, displacement of the end of a sternal fracture required additional treatment. Our results suggest that pneumatic stabilization is comparable to or superior to conventional surgical stabilization.

According to Ahmed *et al.* [1], the tidal volume of flail chest patients is decreased because of pain and atelectasis resulting from alveolar collapse, and this leads to hypoxemia. Trinkle *et al.* [12] identified pulmonary contusion accompanying flail chest as a cause of respiratory failure. The uneven decrease in lung compliance that accompanies pulmonary contusion became an issue in treatment by IPPV without PEEP for anterior flail chest patients. The use of PEEP of 10 cm H_2O or higher in patients with acute-phase multiple organ injuries has traditionally been set on the theory that such PEEP would decrease venous circulation, adversely affect cardiohemodynamics, and cause brain edema or air embolus. We believe that preventing hypoxia and stabilizing cardiohemodynamics are the primary concern for patients with multiple organ injuries. We therefore initiated CPPV in the acute phase for patients with multiple organ injuries associated with severe thoracic injury, including those with anterior flail chest, because we considered it impossible to save the lives of patients who were not treated by PEEP and who developed hypoxia. We maintained circulating plasma volume by fluid replacement and transfusion when hemorrhagic shock was present and dealt with the decreased venous return resulting from PEEP of 10 cm H_2O or higher.

Our survival rate of 93% (40/43) was improved over reported rates of 48-88% [1, 2, 4] by continuation of pneumatic stabilization even during the initial treatment of nonthoracic organ injuries. Under conservative treatment, we were able to treat patients' injuries during the acute stage. The incidence of pneumonia decreased by relieving the pulmonary contusion during the early stage, and the mortality rate fell.

We found that pulmonary contusion with severe hypoxemia (traumatic pulmonary parenchymatous edema) improved with 3-day CPPV management with PEEP of 10 cm H_2O or higher. Treatment by pneumatic stabilization, which lasted for 3 days after arrival, was useful for medial extension and fixation of the ribs and for treatment of hypoxemia secondary to pulmonary contusion. The uneven pulmonary compliance resolved in response to 3-day CPPV in many patients.

On the basis of our findings and experiences, we developed a treatment protocol for anterior flail chest. We start treatment with CPPV in the emergency room. During CPPV, detailed examinations of nonthoracic organs by head and abdominal CT and angiography are performed. Transcatheter arterial embolization and emergency surgery for nonthoracic organ injuries are performed during CPPV.

Efforts make to prevent spontaneous respiration (bucking) in patients in the acute phase because spontaneous respiration causes negative intrathoracic pressure and delays treatment. CPPV management with PEEP of 10 cm H_2O or higher is particularly important during the acute phase because it expands the chest wall outwardly, thereby moving the displaced rib fragments into their normal positions, and it improves pulmonary parenchymatous edema caused by pulmonary contusion. The decreased pulmonary compliance that resulted from pulmonary contusion improved immediately when PEEP of 10 cm H_2O was applied. The incidence of pneumonia decreased, and the outcome of pneumatic stabilization for flail chest improved. Tracheotomy was performed on hospital day 7, approximately, in flail chest patients with head injuries because they experienced distress during weaning from mechanical ventilation.

Our study revealed two important advantages of pneumatic stabilization: pneumatic stabilization does not impose any additional stress on patients with severe acute-phase trauma, and pneumatic stabilization allows physicians to treat severe thoracic and nonthoracic organ injuries other than flail chest. In 2002, Tanaka *et al.* [13] compared surgical stabilization with pneumatic stabilization in flail chest patients and reported that complications (such as pneumonia) were fewer, the period of mechanical ventilation was shorter, and pulmonary function improved to a greater degree in patients treated surgically. Thoracic deformity observed on chest radiographs following treatment by pneumatic stabilization was within the permissible range. One disadvantage of pneumatic stabilization was the need for mechanical ventilatory management for about 2 weeks. Also, it was difficult to identify disturbed consciousness during the period of pneumatic stabilization, when sedatives and muscle relaxants were administered.

Reports since 1996 have shown that surgical stabilization is a complex procedure that is widely indicated. If pneumonia does not develop, the period of mechanical ventilation is shorter with surgical stabilization than with internal pneumatic stabilization. The disadvantage of surgical stabilization is that it imposes further stress on flail chest patients in the acute phase; as a result, physicians cannot focus on the treatment of other thoracic and nonthoracic organ injuries. This has been a factor in the poorer outcome of patients treated by surgical stabilization. There are other disadvantages. Respiratory function may become unstable during surgery, and with PEEP, air may leak outside the thoracic cavity during thoracotomy in the most important period just after injury. As a result, hypoxemia due to pulmonary contusion worsens, and treatment of the pulmonary contusion becomes protracted. Surgical stabilization can also induce intraoperative hemorrhagic diathesis. Fixation of the ribs over a wide area requires detachment of the intercostal muscles and muscles of the chest wall, often resulting in postoperative pain due to intercostal nerve injury.

According to Ciraulo *et al.* [14], flail chest patients often have severe combined thoracic injuries resulting from severe compression of the chest and rapid reperfusion. Flail chest in their patients was often associated with such conditions as massive hemothorax and bronchial disruption, and most of these patients died before arriving at a medical facility. In patients with flail chest complications requiring posterolateral thoracotomy, we shortened the operation time by surgical fixation of only 2-3 ribs in the vicinity of the thoracotomy. We did not isolate the tunica muscularis from the chest wall or surgically fix the fractured ribs after isolating each one. Our clinical experience showed that flail chest is greatly reduced if the center of the anterolateral chest wall is surgically fixed, even if many superior and inferior rib fractures remain. Ahmed *et al.* [1] performed rib fixation with Kirschner's wires and reported that fixation of only 1 of 2 fracture sites per rib is adequate because fractures at 1 site per rib never induce flail chest. Actis Dato *et al.* [3] suggest that "an easier and less invasive surgical stabilization method" is needed. It is not easy to isolate fractured ribs. According to Actis Dato *et al.*, early simple fixation, pneumatic stabilization for several days after surgery, and early weaning from mechanical ventilation yield a favorable outcome with a low incidence of postoperative complications. They also suggest that the plate inserted should be easily extractable.

In conclusion, our experience in treating 43 flail chest patients shows that anterior flail chest can be relieved by pneumatic stabilization alone. Additional treatment may be needed for patients with a displaced sternal fracture. If the period of mechanical ventilation can be shortened to less than 10 days by combining pneumatic stabilization with simple surgical stabilization, flail chest may be resolved without tracheotomy, and patients may resume routine activities a relatively short time.

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