JCS Journal of Chest Surgery
https://doi.org/10.5090/jcs.21.136
pISSN: 2765-1606 eISSN: 2765-1614
J Chest Surg. 2022;55(2):183-187

Case Report

# Nuss Procedure for Surgical Stabilization of Anterior Flail Chest with Mechanical Ventilation Weaning Failure: A Case Report

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**ARTICLE INFO**
**Received** November 8, 2021
**Revised** December 3, 2021
**Accepted** December 13, 2021

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Flail chest is a critical medical condition in which multiple segmentally fractured adjacent ribs cause paradoxical movement of the thoracic cage in patients with severe blunt trauma injury. Surgical stabilization is considered essential in patients who require mechanical ventilation. However, there is no consensus on which surgical procedure to choose among the various available techniques or when to perform surgery. We report the case of a patient with traumatic anterior flail chest due to bilateral multiple fractures of the ribs requiring surgical stabilization in whom weaning from mechanical ventilation had failed. The Nuss procedure using double bars with the bridge technique was performed for chest wall stabilization. The patient was weaned from mechanical ventilation on postoperative day 44 and she underwent bar removal on postoperative day 71. After extensive rehabilitation for multiple trauma, she was discharged successfully. The patient currently shows no recurrence of chest wall depression in outpatient follow-up.

**Keywords:** Flail chest, Trauma, Chest wall, Ribs, Surgery, Case report

## Case report

A 65-year-old woman was admitted to the emergency department after trauma by a hit-and-run accident with a taxi vehicle. At the time of the incident, the car passed over the patient's chest. An off-duty nurse on the other side of the road happened to witness the patient, who sustained head and thoracic trauma. There was no carotid pulse, and bystander cardiopulmonary cerebral resuscitation was performed for 4 cycles. When the paramedics arrived, her carotid pulse was restored, and oxygen was applied until she reached the emergency room. She was in a coma status with her Glasgow Coma Scale score of 6. Flail chest was observed at the site of the anterior and left chest wall depression, as well as head trauma. Her initial vital signs were as follows: respiratory rate, 35 breaths per minute; heart rate, 125 beats per minute; blood pressure, 78/64 mm Hg; oxygen saturation ($SpO_2$), 85%; blood gas pH, 7.276; $pCO_2$, 37.9 mm Hg; $pO_2$, 74.6 mm Hg; and lactic acid, 5.8 mmol/L. Immediate endotracheal intubation and mechanical ventilation were performed. After endotracheal intubation, the patient's $SpO_2$ did not recover. Initial chest radiography revealed bilateral hemopneumothorax with multiple rib fractures bilaterally from the second to seventh rib on the right side and from the second to ninth rib on the left side, as well as a sternal fracture (Fig. 1). Tube drainage by bilateral closed thoracostomy was performed immediately.

Whole-body computed tomography (CT) and abdominal sonography showed the following multiple traumatic injuries in addition to chest trauma: subarachnoid hemorrhage (SAH), blowout fracture in the right medial orbital wall, lung contusion, laceration of the spleen with a pseudoaneurysm of the splenic artery, liver laceration at the left hepatic dome and segment 1, and pelvic bone fractures. Despite massive crystalloid and blood product infusion with the administration of inotropic agents, the patient's vital signs were unstable. As the abdominal distension progressed, the patient underwent angiography, and active bleeding at the pseudoaneurysm site of the splenic artery was found. The patient was admitted to the intensive care unit (ICU) after embolization. For the SAH, since the amount of bleeding was not large, conservative management with strict blood pressure control was planned. Conservative management was also chosen for the liver lacera-

https://doi.org/10.5090/jcs.21.136

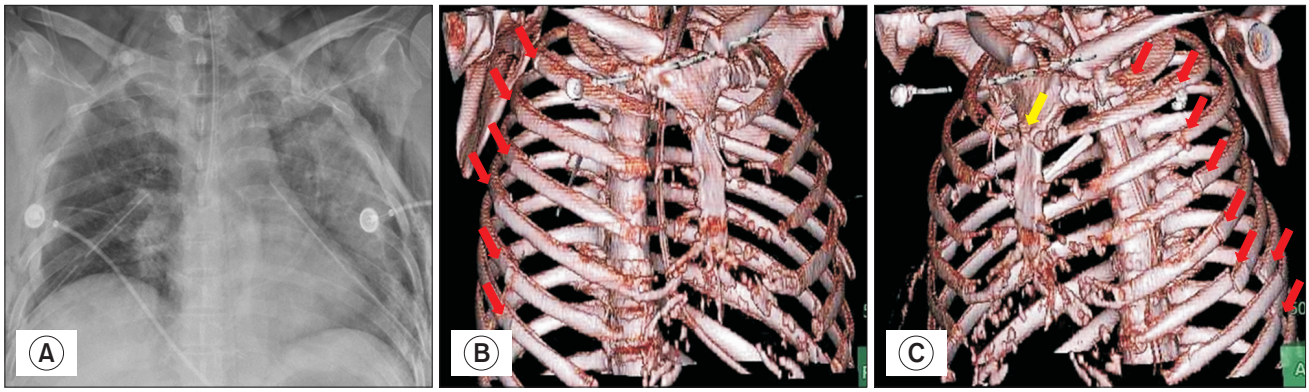


**Fig. 1.** The patient's preoperative chest radiograph and computed tomography (CT) scan with 3-dimensional (3D) reconstructed images. (A) Chest radiography after the initial resuscitation. (B) Oblique view of fractures of the right second to seventh ribs (red arrows) on a 3D-reconstructed CT image. (C) Oblique view of fractures of the left second to ninth ribs (red arrows) and sternal fracture (yellow arrow) on a 3D-reconstructed CT image.

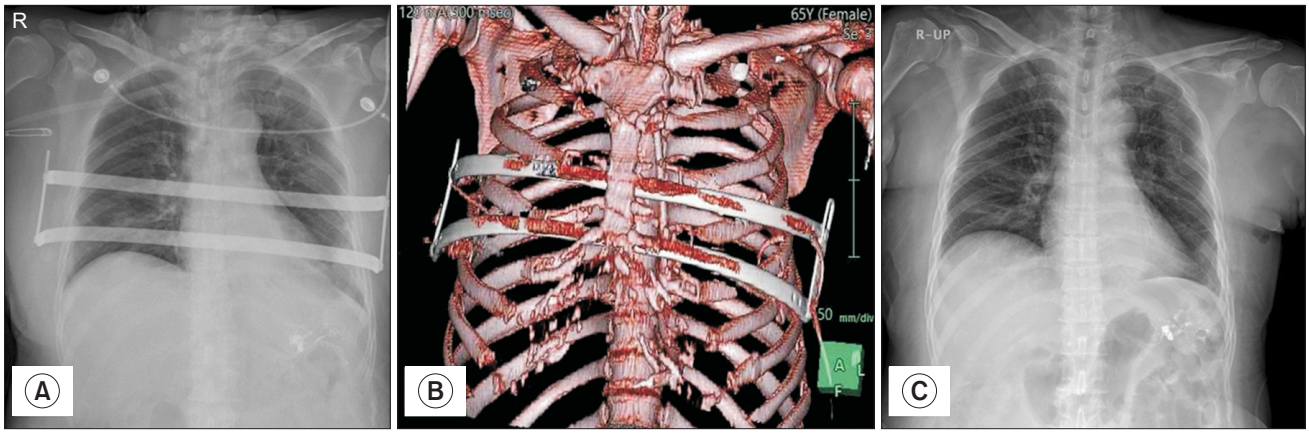


**Fig. 2.** The patient's postoperative chest radiograph and computed tomography (CT) with 3-dimensional (3D) reconstructed images. (A) Immediate postoperative chest radiography after the Nuss procedure for chest wall stabilization. (B) Computed tomography (CT) with a 3D-reconstructed image after the Nuss procedure for chest wall stabilization. (C) Chest radiograph after Nuss bar removal on hospital day 90.

tion and pelvic bone fracture.

With prolonged post-traumatic coma, high-grade diffuse axonal injury was strongly suspected, and the patient underwent early tracheostomy on hospital day 2. The patient's neurological and hemodynamic status gradually recovered without additional active bleeding. However, the patient could not be weaned from mechanical ventilation and showed paradoxical chest wall movement on the anterior and left sides. Surgical chest wall stabilization was planned by the thoracic surgery team and performed on hospital day 9.

The Nuss procedure was performed under general anesthesia in the supine position with both arms abducted. Two 360-mm Nuss bars (Pectus bar series; Hong-eun Medical Inc., Seoul, Korea), two 80-mm bridges, and four 5-mm screws were used in the operation. Two 3-cm-long skin incisions per side were made on both chest walls on the mid-axillary line. Nuss bars were inserted into the fourth and sixth ribs of the right side, and the fifth and seventh ribs of the left side. To prevent abnormal rotation and to support the broad extent of the chest wall segment, a bridge technique was used using 80-mm bridge metal bars to fix the upper and lower bars to each other. Finally, the bars were fixed with the 5-mm screws on the lateral ribs. The wound was closed in layers with Jackson-Pratt drains left into the bilateral pleural cavities after hemostasis.

Flail chest resolved after surgery (Fig. 2). However, the patient was weaned from mechanical ventilation only on postoperative day 44 after the remission of combined severe lung contusion and pneumonia. The T-cannula was

also removed. The patient required further extensive rehabilitation to recover from dysphagia, voiding difficulty, gait disturbance, and decreased respiratory function after the whole-body traumatic injuries. The Nuss bars were removed on postoperative day 71 (Fig. 2). The patient could be discharged on postoperative day 82 and she is currently showing no recurrence of flail chest in outpatient follow-up. Data were collected from reviewing the patient's electronic medical records. This study was approved by the Institutional Review Board of Asan Medical Center (IRB approval no., 2021-1813), and the requirement for informed consent was waived because of the retrospective nature of the study design.

## Discussion

Thoracic trauma is common and occurs in various types [1]. Flail chest, one of the most severe forms of thoracic trauma, is defined as 3 or more contiguous rib fractures with 2 or more breaks per shaft of a rib [1,2]. The destabilized portion of the chest wall leads to locally paradoxical movement, which potentially results in respiratory failure and subsequently, considerable morbidity and mortality [1,2]. Mechanical ventilation with positive end-expiratory pressure is usually required for 7 to 14 days for chest stabilization [1,2]. However, the risk of ventilator-associated pneumonia and the possibility of prolonged ICU care have been serious concerns [3]. Some studies have reported that surgical fixation methods showed better outcomes in lowering the risk of ventilator-associated complications, ICU length of stay, and overall costs compared to nonoperative management of flail chest [4,5]. The indication and timing of surgical stabilization are crucial for the patient; however, no consensus has been reached.

Recent reviews have suggested proceeding with surgical stabilization when respiratory failure, intractable pain and dyspnea, or failure to wean from mechanical ventilation occurs [6,7]. Early surgical intervention (within 24–72 hours after the injury) has also been recommended [6,7]. However, the timing of surgery must be made in the context of the patient's overall clinical condition. Traditional contraindications for surgery are hemodynamic instability, severe traumatic brain injury, unstable spine or pelvic fractures, and pulmonary contusion [6,7].

In the case report presented here, the patient had SAH, multiple organ lacerations with hemodynamic instability, and pelvic fractures. Therefore, surgery for chest wall stabilization seemed risky at that moment. Although the hemodynamic status of the patient stabilized, weaning from invasive ventilation still failed. Therefore, a subsequent operation for the chest wall was contemplated immediately. Conventional surgical stabilization of anterior flail chest, as occurred in our case, by anchoring metal plates with screws seemed difficult and technically demanding. Since the patient had anterior flail chest due to bilateral multiple fractures of ribs with a sternal fracture, we considered that fixation with a metal plate just on the costal cartilage or on the sterno-costal junction could not provide the needed stability and durability. In addition, the conventional procedure requires relatively long skin incisions and extensive tissue dissection. Several cases were reported previously in which the Nuss procedure was performed for surgical stabilization of flail chest with the same concerns (Table 1) [8-16].

A Nuss bar was considered suitable for applying force from below the anteriorly fractured segment, including the sternal body. Unlike the cases reported before, in our case, the chest wall depression was extensive due to the high number of broken ribs. To apply a stable force over a wider range, double bars were installed and fixed with each other using a bridge technique. The Nuss bars were designed to be larger and slightly flatter than the rib cage to prevent the possible pressure at the hinge point pushing the lateral ribs inward, which might aggravate the fractures. As can be seen on chest radiography, the bars were designed to be larger on both sides than when performing general surgery for chest wall deformities. Asymmetrical settlement of the Nuss bars on the left- and right-side thorax was not initially intended. In the operating field, anterior flail chest was symmetrically supported, and it was thought that both bars were inserted parallel to the transverse plane. However, oblique settlement of the Nuss bars was found on the immediate postoperative chest radiograph. Nevertheless, the balance between the bilateral chest walls seemed stable, without depression or paradoxical movement, and consequently did not require an additional correction. The use of bridges to fix the 2 separate parallel bars led to a structure that was stable in itself, which did not require additional fixation of bridges to the ribs. As the part fixed by the bridges became immovable posteriorly, the medial portion of the hinge point formed a stable structure that provided a vertical force supporting the sternum upwards without rotation. Through this method, we achieved simultaneous stabilization and elevation of the chest wall.

In this case, the recovery of the patient's consciousness was slow due to diffuse axonal injury after multiple trauma. The subsequent occurrence of critical illness polyneuropathy and myopathy made weaning the patient from the

**Table 1.** Summary of previously reported cases of the Nuss procedure for flail chest

| Study | Sex | Age (yr) | Site of fractures | Other concomitant medical conditions and trauma | Surgery day | Weaning failure | Operative procedure | Ventilator weaning day | Nuss bar removal day | Outcomes |
|---|---|---|---|---|---|---|---|---|---|---|
| Pacheco et al. [8] (2009) | M | 40 | Every rib on the right side, sternum | Fracture of the right scapula and clavicle, and left femur | NM | + | 3 Horizontal Nuss bars & 1 vertical Nuss bar, right thorax | POD #9 | Suggested POM #6 | Transferred for rehabilitation |
| Ke et al. [9] (2014) | M | 58 | Bilateral second to 4th ribs, sternum | - | HD #2 | NM | 2 Nuss bars, anterior thorax | POD #0 | POM #11 | Discharged on POD #12 |
| | F | 30 | Multiple left anterolateral ribs | Fracture of the pelvis, left acetabulum, and left olecranon | HD #4 | NM | 1 Nuss bar, left thorax | NM | POM #5 | No adverse event |
| | M | 46 | Left second to 5th and 7th ribs, sternum | - | NM | NM | 1 Nuss bar, anterior thorax | POD #0 | NM | Discharged on POD #13 |
| Lee et al. [10] (2014) | M | 35 | Multiple ribs, sternum | Multiple myeloma with diffuse osteopenia, compression fracture of the 11th thoracic vertebral body | 107 days after trauma | - | 1 Nuss bar, anterior thorax | NM | NM | Discharged on POD #97; no adverse event |
| Kim et al. [11] (2015) | M | 44 | Right 1st to 3rd, left first to 5th ribs | Bilateral anterior sternoclavicular dislocation | HD #5 | + | 1 Nuss bar, anterior thorax | POD #1 | Suggested POM #6 | Discharged; no adverse event |
| Akkuş et al. [12] (2015) | M | 55 | Bilateral 2nd to 4th ribs, sternum | Left atrial appendage rupture | HD #5 | + | 1 Nuss bar, anterior thorax | POD #0 | Suggested POM #24 | Discharged on POD #14; no adverse event |
| Nakagawa et al. [13] (2015) | M | 37 | Left 1st to 9th ribs | Fracture of the left clavicle | After HD #4 | + | 1 Nuss bar, anterior thorax | POD #2 | POD #45 | Discharged on POD #23 |
| Lee et al. [14] (2016) | M | 33 | Right 3rd to 7th, left 4th to 7th ribs, sternum | - | After HD #14 | + | 1 Nuss bar, anterior thorax | POD #3 | POM #6 | Discharged on POD #7 |
| Guo et al. [15] (2020) | M | 49 | Bilateral 1st to 7th ribs, sternum | - | After HD #7 | + | 2 Nuss bar, anterior thorax & combined 3 rib fixations with metal plates | POD #3 | Planning POM #12 | Discharged on POD #4; no adverse event |
| Lee et al. [16] (2020) | F | 57 | Bilateral 2nd to 7th ribs due to CPCR | Intramural hematoma of aorta and massive acute pulmonary thromboembolism on ECMO, status post-emergency pulmonary thrombo-embolectomy and hemi-arch replacement of the aorta | 38 days after positive pressure venti-lation | + | 1 Nuss bar, anterior thorax and adhesiolysis via reincising lower part of previous mid-sternotomy | After dis-charge | NM | Discharged in POM #4 with a portable home ventilator, weaned from the ventilator after rehabilitation |

M, male; F, female; NM, not mentioned; POD, postoperative day; POM, postoperative month; HD, hospital day; CPCR, cardiopulmonary cerebral resuscitation; ECMO, extracorporeal membrane oxygenation.

https://doi.org/10.5090/jcs.21.136

ventilator even more difficult. Although we cannot objectively evaluate how much the surgery helped wean her from the ventilator, it was helpful in that the chest wall instability was corrected, other complications did not occur, and the ventilator requirement did not increase. High positive end-expiratory pressure (PEEP), around 13 to 15 cm-$H_2O$, was needed preoperatively due to recurrent atelectasis of both lungs and $SpO_2$ fluctuation. However, after stabilization surgery, we could lower the PEEP step by step and make the patient's respiratory system relatively more stable than it was preoperatively. Therefore, it is judged that corrective surgery for other minor morbidities and bedside physical therapy could be safely performed.

The surgery for Nuss bar removal was initially planned for 3 months postoperatively. However, the patient became symptomatic with chest wall pain during the rehabilitation. To relieve the symptom, removal surgery was performed ahead of the initial plan at postoperative 2.5 months. After rehabilitation, the patient was discharged with no recurrence of chest wall depression. Consequently, Nuss bar removal after approximately 2.5 months could be a feasible option. However, this cannot be generalized from our case, as previous reports suggested 6 months or even 24 months. The removal time differs depending on the patient and the center, as summarized in Table 1. Further research on this question seems to be necessary.

In conclusion, the Nuss procedure provided a favorable surgical outcome, and it could be a good treatment option in patients with severe flail chest and multiple bilateral rib fractures in whom the conventional plating method is unfeasible. The surgical technique should be tailored according to the individual characteristics of the patient.

## Conflict of interest

No potential conflict of interest relevant to this article was reported.

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