Case Series

Tracheobronchial injury after blunt thoracic trauma—lessons to learn in diagnosis, treatment, and postoperative care: a case series

Dennis Aliev[1]^, Isabella Metelmann[1]^, Maren Keller[2], Suzanne Zeidler[3], Gordian Prasse[4], Matthias Steinert[1], Sebastian Krämer[1]^

[1]Section of Thoracic Surgery, Department of Visceral-, Transplant-, Thoracic and Vascular Surgery, University Hospital Leipzig, Leipzig, Germany; [2]Department of Anesthesiology and Critical Care Medicine, University Hospital Leipzig, Leipzig, Germany; [3]Department of Orthopaedics, Trauma and Plastic Surgery, University Hospital Leipzig, Leipzig, Germany; [4]Department of Radiology, University Hospital Leipzig, Leipzig, Germany

Contributions: (I) Conception and design: D Aliev, S Krämer; (II) Administrative support: S Krämer, M Steinert; (III) Provision of study materials or patients: S Krämer, S Zeidler, G Prasse; (IV) Collection and assembly of data: D Aliev, S Krämer, S Zeidler; (V) Data analysis and interpretation: D Aliev, S Krämer, G Prasse; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Dennis Aliev. Section of Thoracic Surgery, Department of Visceral-, Transplant-, Thoracic and Vascular Surgery, University Hospital Leipzig, Liebigstr. 20, 04103, Leipzig, Germany. Email: dennis.aliev@medizin.uni-leipzig.de.

Background: Tracheobronchial injury (TBI) is the subsuming term to describe rare and mostly traumatic damage to the tracheobronchial tree. Prehospital mortality is significant. TBI patients may face delayed diagnosis, challenging perioperative care, and prolonged recovery. The focus of this case series is to identify issues that represent common hurdles and potential problems in the diagnosis, treatment, and postoperative care of patients with TBI.

Case Description: This is a single-center retrospective case-series study of four patients who experienced TBI following blunt thoracic trauma in the study period from January 1, 2020, to December 31, 2023. The mean age of the patients was 48 years, with patient age ranging from 24 to 59 years. One patient was female and the other three were male. Two patients sustained injuries to the main bronchi, while the others sustained injuries to more peripheral parts of the tracheobronchial tree. Three patients were secondary transfers to our hospital, while the other was a primary admission. All four patients underwent surgery for their TBI. The duration of hospitalization ranged from 10 to 60 days. The two patients with main stem bronchus injury required the longest hospitalization. The same two patients required extracorporeal membrane oxygenation therapy. We experienced no mortality, and all patients were discharged for post-hospital rehabilitation.

Conclusions: TBI management requires a multidisciplinary and experienced team. One must be aware of the classic clinical presentation: dyspnea, soft tissue emphysema, and hemoptysis. Cases in which a history of trauma is associated with dyspnea and/or chest wall/mediastinal emphysema require early bronchoscopy as the diagnostic gold standard. The use of "Minimum-intensity projection" (MinIP) reconstructions can help identify TBI in computed tomography scans. Extracorporeal membrane oxygenation therapy is to be considered in selected cases. Surgical repair must focus on preventing parenchymal loss by reconstructing the bronchial defect while avoiding anatomical resection. Postoperative care should consider the possibility of bronchial denervation and its potential complications.

Keywords: Tracheobronchial injury (TBI); blunt thoracic trauma; bronchoscopy; denervation; case series

Submitted Apr 26, 2024. Accepted for publication Jul 05, 2024. Published online Sep 09, 2024.
doi: 10.21037/jtd-24-579
View this article at: https://dx.doi.org/10.21037/jtd-24-579

^ ORCID: Dennis Aliev, 0009-0008-9224-6505; Isabella Metelmann, 0000-0003-1963-8189; Sebastian Krämer, 0000-0003-4867-8884.

Introduction

Tracheobronchial injuries (TBIs) represent a challenging spectrum of traumatic conditions that demand a nuanced understanding of both their clinical presentation and management.

The incidence of TBI is estimated to be between 0.2% and 5% in chest trauma patients (1). This rarity is coupled with a high prehospital mortality of up to 80% (2). Risk factors for experiencing traumatic TBI include congenital tracheal abnormalities, female gender, and age >65 years (1). Management strategies for TBI vary, necessitating the involvement of an experienced and multidisciplinary team to promptly diagnose and treat these conditions, thereby minimizing the risk of complications and preventing the loss of lung function. The purpose of this case series is to focus on aspects, that represent common hurdles and potential problems in the diagnosis, treatment, and postoperative care of patients with TBI. We present this article in accordance with the AME Case Series reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-579/rc).

Case presentation

This is a single-center retrospective case-series study from an academic trauma referral center. We identified all cases of traumatic TBI referred to our hospital from January 1, 2020, to December 31, 2023, through an in-house database search (n=15). We excluded minors, patients with traumatic airway injuries caused by sharp objects, such as knives, and any iatrogenic lesions. This resulted in four patients being included in the study (ICD-10: S27.4/S27.5). One patient is female and the other three are male. Age at the time of the incident ranged from 24 to 59 with a mean of 48 (median of 54) years (*Table 1*). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013), and was approved by the local ethics committee at the Medical Faculty, University of Leipzig (No. 032/24-ek). All participants consented to the use of their personal data and accompanying images for research purposes by signing the hospital's admission agreement.

Highlight box

Key findings

- Bronchoscopy is the gold standard for diagnosing tracheobronchial injury (TBI). Minimum-intensity projection (MinIP) reconstructions can aid in diagnosing TBI in computed tomography (CT) scans. Extracorporeal membrane oxygenation (ECMO) therapy should be considered in selected cases. Postoperative recovery may be affected by bronchus denervation.

What is known and what is new?

- TBI represent a rare and challenging spectrum of traumatic conditions coupled with a significant prehospital mortality.
- A triad of a history of chest trauma, dyspnea, and soft tissue/mediastinal emphysema requires bronchoscopic evaluation. MinIP reconstructions can aid in diagnosing TBI in trauma CT scans. Denervation is a possible complication.

What is the implication, and what should change now?

- We suggest that a triad of a history of chest trauma, dyspnea, and soft tissue or mediastinal emphysema requires bronchoscopy as soon as the patient's condition permits.
- TBI patients should be screened postoperatively for signs of denervation by radiography and bronchoscopy.

Case 1, already reported on (2)

A 57-year-old blacksmith was accidentally struck in the left upper chest, jaw, and head by a hammer-like device while at work. Stable from a respiratory standpoint, he was admitted to the nearest hospital where computed tomography (CT) scan revealed fractures of the left clavicle and second rib, left pneumothorax, chest wall emphysema, and left pulmonary contusion and myocardial contusion (*Figure 1*). The patient received a left chest tube. He was then transferred to our clinic, the University Hospital of Leipzig (Academic Trauma Referral Center). The primary survey was initiated in the trauma room according to the Advanced Trauma Life Support (ATLS) guidelines (3). Physical examination revealed a cardiopulmonary stable patient with severe pain and subjective shortness of breath. The patient had adequate SpO_2 (100% without supplemental oxygen), a heart rate of 78 bpm, blood pressure of 143/87 mmHg, and Glasgow Coma Scale (GCS) 15.

He had a 1 cm bruise on his head, a 3 cm bruise mark on his left calf, and a 4–5 cm wound on his left ventral upper thorax paramedian to the manubrium sterni with connection to the pleural cavity. Breath sounds were reduced over the projection of the left lung. Extended focused assessment with sonography for trauma (eFAST) showed no evidence of free fluid in the abdomen or lacerations of the abdominal organs. eFAST confirmed a persistent left-sided pneumothorax.

An hour after admission, video-assisted thoracoscopic surgery (VATS) was performed on the left chest to explore the extent of the injury and to remove the hematoma within

Table 1 Patient information including trauma data

Case	Gender, age (years)	Trauma mechanism	Injury site	ISS	AIS thorax	Hospitalization (days)	Intensive care unit days	ECMO days
1	Male, 57	Occupational forging trauma	Bifurcation left upper lobe	13	2	10	2	No ECMO therapy
2	Male, 59	Car against tree trauma	Left main bronchus	29	5	42	19	7
3	Female, 24	Bike against tram trauma	Middle lobe bronchus	50	2	11	2	No ECMO therapy
4	Male, 51	Occupational overrolling trauma	Right & left main bronchus	33	5	60	60	7

ISS, Injury Severity Score; AIS, Abbreviated Injury Scale; ECMO, extracorporeal membrane oxygenation.

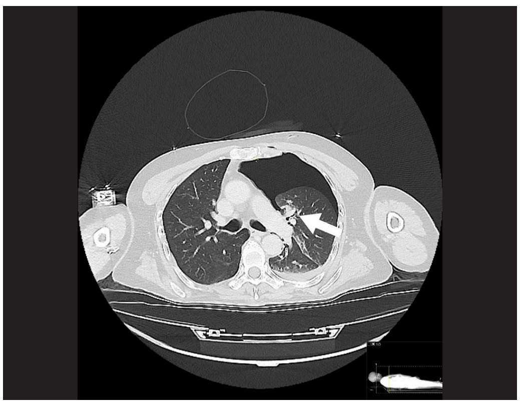

Figure 1 Trauma scan of Case 1. The axial slice shows a pneumothorax on the left side and non-specific trauma-associated alterations in the left proximal bronchus tree. Arrow indicates lesion location.

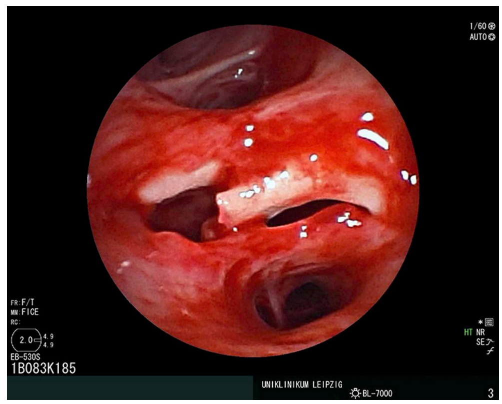

Figure 2 Case 1, bronchoscopy after initial video-assisted thoracoscopic surgery. Injury at bifurcation of left upper lobe bronchus.

the thoracic cavity. Intraoperatively, the hilar structures as such appeared intact, but as a result of the trauma, the vessels looked dissected down to the segmental level, especially the pulmonary veins. A pericardial window was created, and parts of the fractured rib were removed. No bronchial injury has been seen so far. At the end of the operation, the left lung was re-ventilated. Macroscopically, an injury of the left upper lobe bronchus was observed.

High fistula volumes, massive bronchial secretions, and blood in the endotracheal tube were also noted by the anesthesiologist. A high-quality bronchoscopy performed by a dedicated bronchoscopist with quality equipment confirmed the macroscopic findings and provided a more detailed picture of the underlying problem. A rupture was identified at the bifurcation of the upper lobe bronchus to the B1/B2/B3 segmental bronchi and the B4/B5 segmental bronchi (*Figure 2*). The pleural cavity was seen through the site of the rupture. An endoscopic intervention was ruled out in favor of a subsequent thoracotomy. The lesion was sutured with interrupted 4×0 polydioxanone (PDS). An autologous vascularized pediculated pericardial patch was placed over the repaired area through a fixating suture (4×0 PDS). The patient was admitted to the intensive care unit. The initial fistula volume was 120 mL/min and decreased steadily. EzPAP®-therapy, a positive airway pressure system, was started to prevent atelectasis. Postoperative bronchoscopy and radiographic findings were satisfactory.

The emphysema regressed. On the second postoperative day, the patient was transferred to a regular surgical ward. A small left pleural effusion and dystelectasis in the left middle and upper field were noted but also improved. After an otherwise uncomplicated recovery, supported by respiratory physiotherapy, the patient was discharged on day ten. The patient's general condition gradually improved and post-

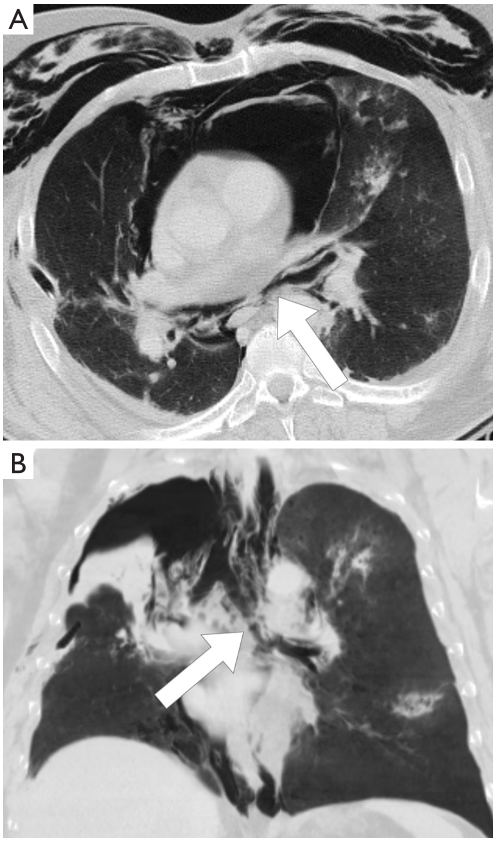

Figure 3 Initial computed tomography scan of Case 2: (A) axial reconstruction showing an irregular margin of the left main bronchus, mediastinal and subcutaneous emphysema; (B) coronal minimum-intensity projection reconstruction facilitates depiction of airway borders and shows irregularities of the left main bronchus wall. Arrows indicate lesion location.

hospital rehabilitation was planned.

Lesson I: identifying TBI

High-quality bronchoscopy is the gold standard for diagnosing TBI in any case of clinical suspicion.

Case 2

A 51-year-old man driving under the influence of alcohol crashed his car into a tree at approximately 50 km/h. He was found ejected from the vehicle in a stable and conscious condition. The patient was taken to the nearest hospital for an initial trauma survey including a CT scan. Due to clinical deterioration, he underwent endotracheal intubation, placement of two right-sided chest tubes, and secondary transfer to our hospital. On arrival at the emergency department, the primary survey started in the trauma room according to the ATLS guidelines. The patient was hypoxic (PaO_2 of 70 mmHg/9.3 kPa on 100% supplemental oxygen), tachycardic at 103 bpm, had a blood pressure of 145/80 mmHg with ongoing catecholamine therapy, and a GCS of 3. There were no external signs of injury to the head, thorax, abdomen, or pelvis. Breath sounds were decreased over the left lung. The chest was stable to compressions. eFAST was inconclusive due to free abdominal air. A first bronchoscopy was inconclusive, but indicated an obstruction of the left main bronchus. CT scan showed bilateral pneumothorax, bilateral cervical and thoracic emphysema, massive mediastinal emphysema, pneumopericardium, pulmonary hemorrhages, and massive amounts of free abdominal with a right-sided rupture of the diaphragm (*Figure 3*). A second bronchoscopy confirmed an injury to the left main bronchus, consistent with the previous suspicious radiologic findings. The patient received a chest tube on the left side. Nitric oxide was used in an attempt to improve the patient's oxygenation. Hypoxia improved with this therapy. However, one-sided lung ventilation, required for surgical repair, was considered unsuitable for the patient under the given circumstances. Thus, the decision was made for the application of venovenous extracorporeal membrane oxygenation (vvECMO). Due to the extensive nature of the injury, an interventional approach was ruled out in favor of surgery. A left-sided thoracotomy followed. The pneumoperitoneum was first addressed by opening the diaphragm. vvECMO flow improved immediately, while no intraabdominal organ perforation was seen nor smelled. Preparation of the lung hilus showed the extent of the TBI. A longitudinal tear of the left main stem bronchus was seen centrally to a second circumferential tear of at least 300°, with only the membranous portion intact. To prevent stenosis, the circumferential lesion was repaired first with two continuous sutures (4×0 PDS), one for the anterior wall and one for the posterior wall. The longitudinal lesion was sutured with interrupted 4×0 PDS. A pericardial patch was placed over the anastomosis and secured with fibrin sealant. An intraoperatively detected, initially covered, arterial hemorrhage of the costobronchial trunk was controlled with prolene sutures. The patient was transferred to the intensive care unit, to support accelerated weaning. The patient was expected to have a prolonged hospital stay, so a percutaneous tracheostomy was performed the next day. Emphysema improved gradually.

Dystelectasis and failure of bronchial clearance from the left lung became a major problem. Initially, the left lower lobe was atelectatic. Secretions were evacuated via bronchoscopy several times a day through the slightly stenotic anastomosis. Evidence of *Staphylococcus aureus* was found in the tracheal secretions. This presumed wound infection was treated with flucloxacillin. An infectious pericardial effusion was treated interventionally with pericardiocentesis by the cardiology department. Ventilation improved over time. vvECMO was stopped on day seven. The tracheostomy tube was removed on day eighteen. With bronchoscopic evidence of persistent post-anastomotic secretion retention, but in an overall improved condition, the patient was discharged from intensive care on day 19. After an otherwise uneventful recovery supported by respiratory physiotherapy including mucus mobilization posturing based on Nelson´s descriptions (4), he was discharged on day 42 for post-hospitalization rehabilitation. Follow-up bronchoscopy continued to show mild anastomotic stenosis without clinical deterioration. A chest X-ray showed decreased opacity of the left lung. The patient's further development was satisfactory.

Lesson II: ensuring patient oxygenation

Consider all perioperative options for optimal oxygenation, including extracorporeal membrane oxygenation (ECMO) therapy, to facilitate good surgical conditions and the best possible therapeutic outcome.

Case 3

A 24-year-old woman was admitted to our hospital following an accident in which she was hit by a tram coming from the right side while riding a bicycle. The emergency team reported the following initial findings: conscious, no airway, breathing problem as follows: 89% SpO_2 without supplemental oxygen, reduced breath sounds on the right side of the chest, no circulatory problem, pain all over the right side of her body, retrograde amnesia.

On arrival at the emergency department, the primary survey started in the trauma room according to the ATLS guidelines. It revealed a stable patient with persistent breathing issues (92% SpO_2 on 4 L/min of supplemental oxygen), tachycardia of 120 bpm and a blood pressure of 114/86 mmHg. GCS was 15. She had multiple cuts and lacerations to the head, upper and lower extremities. No external signs of injury to the abdomen or the chest cavity. Suspicion of right-sided pneumothorax due to decreased breath sounds. eFAST consolidated this finding but was inconclusive for the abdomen. CT showed an extensive intraperitoneal hematoma, a grade 4 liver injury according to the American Association for the Surgery of Trauma (AAST) classification (5), a lesion of the pancreatic head, a fracture of the anterior pelvis, and a hematoma of the galea, without evidence of associated intracranial hemorrhage. Chest CT scan showed an extensive tension pneumothorax on the right side with a mediastinal shift to the left and an almost complete collapse of the right lung with signs of laceration, pneumatoceles, and (secretion) consolidations in the collapsed right lung—especially in the basal parts with a minor pneumothorax on the left side and hemothorax. Furthermore, a pronounced cervical pneumomediastinum up to the cranial base in the retropharyngeal space, a right-sided soft tissue emphysema, irregularities of the middle third of the oesophagus, and serial dislocated rib fractures—first to seventh ribs—were seen. To this point, no TBI has been identified. Oesophagoscopy ruled out oesophageal injury (*Figure 4*). After chest tube placement, the patient's extensive abdominal trauma was treated surgically.

With an intraoperative air leak of up to 3 L/min, a subsequent bronchoscopy immediately after abdominal surgery revealed several small lesions, covered by tissue, in the depth of the middle lobe bronchus (*Figure 5*). The following day, another bronchoscopy was performed, ruling out a potential interventional approach in favor of a thoracotomy on the same day. Intraoperatively, the lung showed signs of trauma with subpleural hematoma and contusion. Lung parenchymal tears were visible near the course of the pulmonary artery within the oblique fissure. The hematoma was evacuated. After removal of the local lymph nodes, the injury became visible. The transmural lesions at two sites of the middle lobe bronchus were found to be contiguous with intact mucosa bridging them. Thus, the defect was significantly larger than initially thought during bronchoscopy. The bronchus was reconstructed with interrupted 4×0 PDS. There were no intraoperative complications. The patient was admitted to the intensive care unit postoperatively. She was extubated the same day. The postsurgical radiographic findings were satisfactory. Initial dystelectasis and secretory infiltrations improved rapidly. On the second postoperative day, the chest tube was removed, and she was transferred to a regular surgical ward. After an otherwise uncomplicated recovery, supported by respiratory physiotherapy, she was discharged on day eleven for post-hospitalization rehabilitation. Follow-ups showed satisfactory progress.

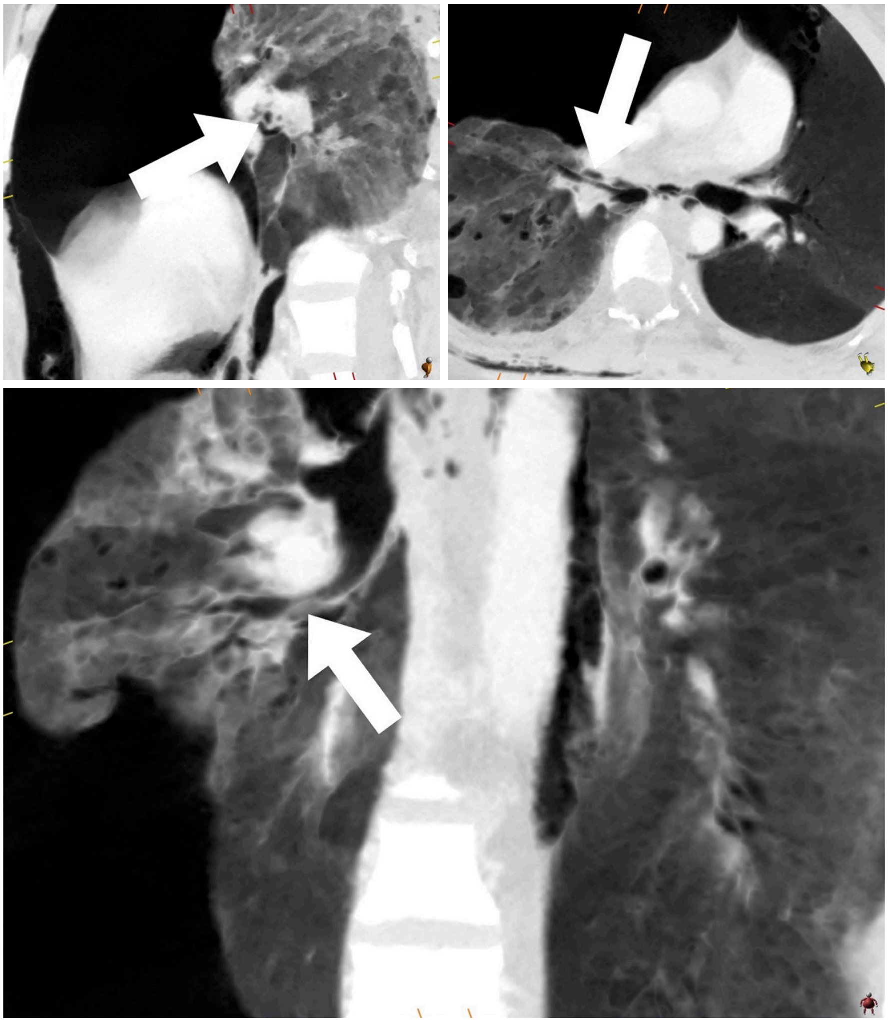

Figure 4 Multiplanar reconstruction of the initial computed tomography scan of case 3 as minimum-intensity projection, depicting a transient reduction in diameter of the middle lobe bronchus and a small collection of air adjacent to this location as indirect hints to a possible injury to the airway wall. Arrows indicate lesion location.

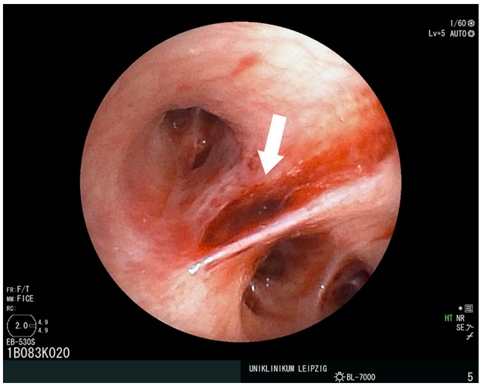

Figure 5 Case 3, bronchoscopy after laparotomy. Injury at middle lobe bronchus, indicated by white arrow.

Lesson III: *preventing parenchymal loss*

Always try to preserve all functional lung tissue through bronchoplastic reconstruction. Avoid anatomical resection.

Case 4

A 59-year-old man was run over by a large industrial cable reel while at work. He was admitted to a supra-regional trauma center, where a CT scan revealed multiple fractures of the spine, the sternum, the right humerus, serial rib fractures of the ribs C1–C8, hemothorax, and right-sided pneumothorax. The right mainstem bronchus was seen to be injured. The man received two chest tubes one on each

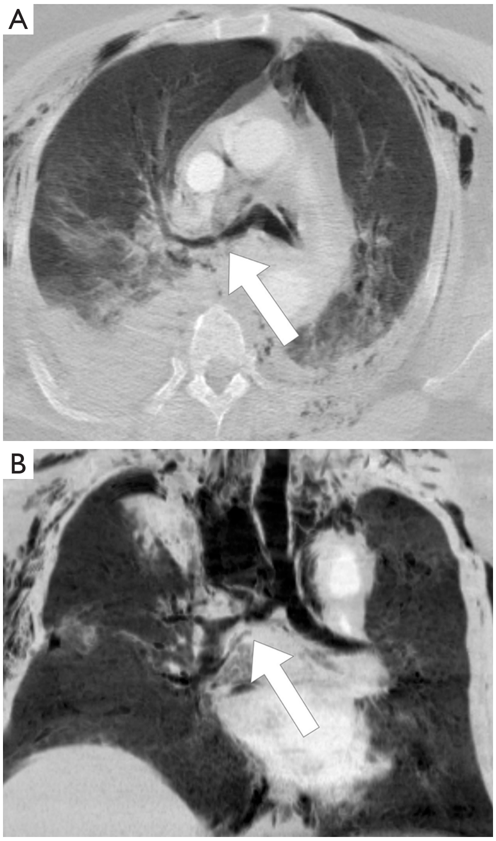

Figure 6 Case 4, computed tomography scan at admission to the trauma center. Axial (A) and coronal (B) minimum-intensity projection reconstructions depicting reduction in diameter, irregular airway borders and local mediastinal emphysema directly adjacent to the right main bronchus. Arrows indicate lesion location.

side and was intentionally main stem intubated on the left side. In collaboration with our hospital, vvECMO therapy was initiated on-site with a planned secondary admission to our clinic. The patient was then transferred to our maximum care hospital. On arrival, the patient underwent a further CT scan.

It confirmed the findings of the external scan, but also showed cervical, thoracic, and abdominal emphysema, as well as epidural emphysema of the spine (*Figure 6*).

Bronchoscopy was performed to confirm the suspected injury to the right main stem with near-total destruction just distal to the main carina. Due to the extent of the injury, an interventional approach was ruled out in favor of surgery. A thoracotomy was scheduled for the same day. Intraoperatively, the right lung was found to be heavily hemorrhaged and emphysematous. The mediastinal area

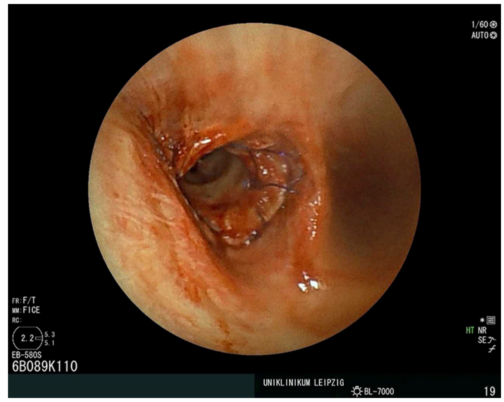

Figure 7 Case 4, initial postoperative bronchoscopy. Anastomosis of the right main bronchus seen.

between the trachea and the right main bronchus was severely destroyed. Further mobilization of the tracheal bifurcation revealed an additional tear in the membranous portion of the left main bronchus. Both lesions were sutured with interrupted 3×0 PDS. A total of 16 interrupted sutures were placed. The patient was transferred to the intensive care unit. After thoracotomy, the patient underwent a surgical tracheostomy and surgical treatment of the spinal injuries. Initial postoperative bronchoscopy was satisfactory (*Figure 7*). A postoperative CT scan showed a total atelectasis of the right lung, which later developed into chronic dystelectasis. Emphysema improved. Further postoperative bronchoscopies revealed large amounts of secretions in both bronchi (*Figure 8*). Persistent post-traumatic dehiscence of the right upper lobe bronchus was noted.

Due to its small size, no intervention was made, and the lesion was monitored. The left side of the bronchial system was seen to be anatomically intact. The vvECMO therapy was stopped on postoperative day seven. Ventilation of the right lung improved. The patient was closely monitored radiographically and bronchoscopically over the following weeks. It was repeatedly noted that it was not possible to elicit a cough reflex triggered from the right bronchus. Secretions on the right side remained abundant, thick, and static. The patient was decannulated on postoperative day 43. Before discharge, the amount of secretion normalized, and bronchial clearance improved. A small parenchymal defect of the right upper lobe bronchus of no obvious clinical significance was still reproducible via bronchoscopy. The patient was discharged from intensive care on day 60 for postoperative rehabilitation. Due to the recency of this

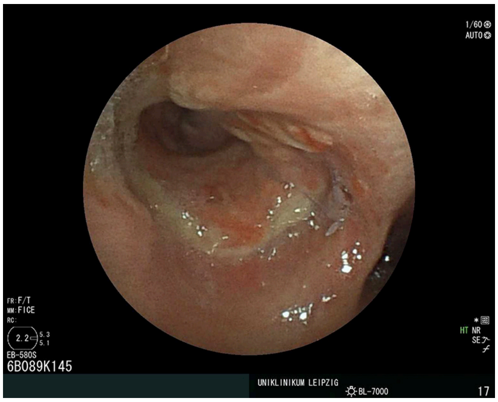

Figure 8 Case 4, follow-up bronchoscopy. Anastomosis site with secretions and fibrinous plaques.

case, no follow-up data is available yet.

Lesson IV: denervation and impairment of bronchial clearance

The more central the location of the lesion, the more the postoperative course is influenced by problems of altered secretion clearance due to possible traumatic denervation of the bronchial mucosa.

Discussion

Few, but well-regarded literature exists on TBI (1,6-8). It is not the purpose of this case series to provide a comprehensive review of the literature. Rather, we aim to focus on four specific aspects of the diagnosis, treatment, and post-operative care of patients with TBI. These four aspects serve as lessons. They are (I) identifying TBI, (II) ensuring patient oxygenation, (III) preventing parenchymal loss, and (IV) denervation and impairment of bronchial clearance. Each of these aspects represents a problem, that we have encountered and that other clinicians may face as potential pitfalls.

Lesson I: identifying TBI

Up to 68% of all TBI are diagnosed with a delay (9). This multifactorial phenomenon can be explained by the size of the lesion, its location, and the different means of diagnosis, among other considerations (1). Although radiography and CT are established diagnostic tools in emergency departments, they are not the preferred method for diagnosing TBI, especially for smaller lesions. However, unspecific signs of injury can be seen in the form of pneumothorax, chest wall or mediastinal emphysema, and bronchial displacement (7,10). Complete tears of the main bronchi may result in the pathognomonic "fallen-lung sign" (11). In cases two (C2) and four (C4) the CT scan provided good indicators of a possible TBI, which was later confirmed by bronchoscopy. However, in cases one (C1) and three (C3) we have encountered the problem of delayed diagnosis. In both cases, the initial radiological findings (pneumothorax and chest wall emphysema) were seen as unspecific and the possibility of TBI was not considered. To improve the detection rate of TBI and optimize treatment planning, secondary reconstructions, utilizing minimum-intensity projections, "MinIP", can be beneficial (12).

In MinIP reconstructions (*Figures 3,4,6*), the minimum value of an arbitrary slice thickness is displayed, thus emphasizing the air within the bronchial tree, and providing visual contrast to the surrounding tissue. Multiplanar reconstructions, aligned to the bronchial anatomy can help to identify areas of irregular airway walls, hematoma, transient airway diameter restriction, or emphysema adjacent to traumatic alterations of the anatomy. CT-based virtual bronchoscopy is an alternative secondary reconstruction technique. While helpful in planning the bronchoscopy procedure, the reconstruction parameters have a large influence on the final result, which may lead to inconclusive results (13). In the case of trauma scans, where artifacts due to metal devices, invasive breathing, or patient movement may reduce the overall image quality, MinIP is likely to be able to produce more conclusive results. Subsequent bronchoscopy after large intraoperative air leakage, itself suggestive of TBI (8), led to the diagnosis of TBI in C1 and C3 (*Figure 5*). Flexible bronchoscopy has long been considered the gold standard for TBI diagnosis (14), as was also seen in our cases. However, diagnosis also depends on the experience of the examiner (7,15). As seen in C1 and C2, the initial bronchoscopy was inconclusive, and it had to be repeated by an experienced pulmonologist to confirm the diagnosis (*Figure 2*). Qualified bronchoscopy in diagnosis and follow-up requires experience and high-quality equipment (*Figures 7,8*). Standardization is one way of reducing inter-examiner variability. However, as a rare entity, TBIs are only briefly addressed in the 2018 version of the ATLS guidelines. This is despite an increase in their incidence over the past three decades, partly due to an increase in motor vehicle accidents and a concurrent improvement in emergency infrastructure (16). For the

11th edition of the ATLS guidelines, we see the need to further elaborate on this specific chapter of the Guidelines. As specific signs of TBI are scarce, many authors have suggested specific constellations of symptoms as indicators of these rare injuries (10). Palade and Passlick proposed a triad that should raise a high index of suspicion for TBI.

The triad consists of cyanosis, soft tissue/mediastinal emphysema, and dysphonia. Dyspnea and pneumomediastinum are the most common symptoms of TBI with an incidence of up to 100% for the dyspnea and up to 85% for soft tissue emphysema (17). Pneumothorax occurs in up to 70% of cases (18). Dyspnea played a major role in all cases except C1. Whereas all four of our cases presented with pneumothorax and pneumomediastinum. Coupling these red flags with the mechanism of injury may increase the rate of discovery of TBI. Several possible mechanisms have been described for TBI (19,20). When treating patients with a history of high-impact trauma to the chest, as in our four cases (*Table 1*), the emergency team should especially consider the possibility of such a TBI. Many authors have suggested bronchoscopy in patients with possible TBI as soon as their condition permits (6,15). Early diagnosis and treatment of TBI are thought to lead to a better prognosis (10,21). Coupling the mechanism of injury with the most common symptoms (red flags), we suggest that TBI should always be suspected and therefore investigated by flexible bronchoscopy, if possible before the administration of general anesthesia, as soon as the patient's condition permits in patients with the following constellation: history of chest trauma, dyspnea, and/or soft tissue/mediastinal emphysema.

Lesson II: ensuring patient oxygenation

With respiratory deficits being present in up to 100% of all cases (17), ensuring patient oxygenation is a key part of TBI management. Up to half of all patients with TBI receive a chest tube either before hospital admission or in the emergency room (ER). In addition, nearly 60% of patients are intubated before hospital arrival (21). In our four cases, all patients either arrived with or received one or more chest tubes in the ER. Two of our patients (C2 & C4) were intubated before arrival at our hospital. The patient in C3 received supplemental oxygen instead, which improved her SpO_2.

Patient 1 did not need supplemental oxygen upon the first survey at the ER. In one of the proximal TBI cases, C2, an attempt was made to improve oxygenation with nitric oxide. Although routine use of nitric oxide in patients with acute lung injury and acute respiratory distress syndrome is not recommended, nitric oxide has been shown to provide at least short-term benefits for oxygenation (22). Inhaled nitric oxide improves oxygenation by vasodilation of ventilated lung parts, thus decreasing shunting and improving ventilation to perfusion ratio (23). Ultimately, both patients 2 and 4 received vvECMO therapy. In challenging ventilatory situations or during surgery, ECMO serves as a valuable tool for efficient gas exchange, and it can also be a backup option for managing life-threatening TBIs in multisystem trauma patients (24). However, it should be noted that ECMO is a resource-intensive therapy option that requires high expertise (25). Moreover, surgeons must be aware of the necessary anticoagulant therapy during ECMO application and the associated higher peri- and postoperative risk for bleeding. In C2, ECMO therapy was initiated in our hospital. In C4, the severity of the injuries required immediate use of vvECMO therapy. A specialized team from our hospital was sent to start this therapy before transfer to ensure maximum safety. Inter-hospital communication and cooperation are key to TBI management. Later, during the recovery process, all patients underwent respiratory physiotherapy. In addition, all four patients were sent to specialized rehabilitation centers after discharge. They are regularly followed up.

Lesson III: preventing parenchymal loss

Conservative treatment options are becoming increasingly relevant in the management of TBI. Grewal lists spontaneous breathing, minimal mechanical ventilation, and absence of mediastinal or esophageal compromise as indications for conservative approaches. None of our patients met these criteria (1). Surgery remains the treatment of choice for most cases of TBI, as the prognosis also seems to favor surgical treatment over conservative approaches (9). However, for small postoperative dehiscence in C4, we chose a watch-and-wait approach with continuous bronchoscopic surveillance. Similar strategies are used for minor asymptomatic dehiscence in lung transplant patients (26). According to ATLS, thoracotomy is the gold standard for emergencies (3). VATS approaches to treating TBI remain the exception, with Yu and Laohathai presenting the only case of intentional bronchial repair using VATS (27). They concluded that VATS repair is feasible as an alternative approach to thoracotomy. VATS may be more beneficial when treating patients with flail chest (28). In C1, the initial exploration was carried out by video thoracoscopy, although the confirmation of a TBI led to a change to thoracotomy, as was the initial approach in C2–C4. We chose thoracotomy for its advantages in time efficiency, flexibility of management, and controllability of the intraoperative findings. Although there are reports of segmentectomy, lobectomy, and pneumectomy being performed in patients with TBI (29), the initial approach to any TBI should be either bronchial repair or anastomosis of the injury. Depending on the injury's size, location, and extent, the suturing technique might defer from one case to another. Our use of PDS monofilament sutures is in line with other reported repair techniques using absorbable sutures (30). In C1 and C2, pericardial patches covered the repaired areas. Pericardial patches, which provide high wall stability and airtightness, are used in tracheobronchial tree repairs to reinforce the anastomosis (15,17). There is no universal approach to treating TBIs. In general, patients should be treated by centers with maximum expertise.

Three of our cases (C1, C2, C4) reached our maximum care hospital after initial admission to an external hospital that did not have the expertise or capacity to manage such cases in a way that would provide the best possible therapeutic outcome. TBI management requires strong inter-hospital and interdisciplinary communication and cooperation.

Lesson IV: denervation and impairment of bronchial clearance

All patients underwent repeated postoperative physical, radiographic, and bronchoscopic evaluation to ensure optimal recovery. In cases C2 and C4 our patients had prolonged recovery times. Patient 2 was hospitalized for 42 days, while patient 4 was hospitalized for 60 days. This represents a 4- and 6-fold increase, respectively, compared to patient 1 (10 days) and patient 3 (11 days). Both cases had an injury to the main stem bronchus in common. In C4, both main bronchi were injured. In both C2 and C4, the patients experienced increased secretions distal to the lesion, which required repeated bronchoscopic evacuation (*Figure 8*). Patient 4 developed total atelectasis of the right lung postoperatively. Although postoperative mucus accumulation and atelectasis are commonly reported in the literature on TBI (31), impaired bronchial clearance is rarely explicitly described. As a well-researched field, lung transplantation serves as a useful analogy for an iatrogenic TBI model, albeit with several differences due to its "atraumatic" nature, making it not entirely comparable. Bronchial clearance is known to be impaired in the long term in patients who have received a lung transplant (32). Short-term bronchial clearance was also impaired in canine models (33). The impairment of bronchial clearance in lung transplant patients was contextualized with observations of changes in bronchial clearance in dogs (34). Paul hypothesized that denervation and devascularization may be possible causes of this impairment. In a different canine model, denervation was further evaluated by transection and reanastomosis of the left main bronchus (35). Postoperative lung clearance half-times were found to be prolonged by three days.

In lung transplant settings denervation is caused by vagal nerve transection (36). The tracheobronchial tree is surrounded by sympathetic and parasympathetic fibers, including those from the vagal nerve in the form of the pulmonary plexus. Damage to this system impairs cough, bronchial clearance, and the Hering-Breuer reflex (37). We believe that traumatic transection of this plexus occurred in C2 and C4 leading to the seen symptoms.

Accumulation of secretions is associated with an increased risk of pneumonia and should be taken seriously (38). As a protective respiratory reflex and adjunct to bronchial clearance (39), cough has been extensively studied in the context of lung transplantation (37). It is known that there is an inability to elicit a cough reflex distal to the anastomosis (40). Similar effects were observed in one of our cases. Postoperative bronchoscopies revealed that the cough reflex on the right side of patient C4 could not be triggered, while the left side was physiological. This supports our hypothesis that denervation of the tracheobronchial tree distal to the TBI is a reproducible problem. It is worth noting that in lung transplant patients, denervation may not be permanent (37). This can also be expected in TBI, especially when there is not a complete transection of the bronchi. In cases with smaller lesions, such as those seen in C1 and C3, no significant symptoms of denervation have been observed. We believe, however, that to prevent complications, all TBI patients should be screened postoperatively for signs of denervation by radiography and bronchoscopy.

Conclusions

Management of TBI requires a multidisciplinary and specialized team. Intra- and interhospital communication and cooperation are key. To reduce the number of delayed diagnoses of such injuries, we propose a constellation consisting of: a history of chest trauma, dyspnea, and/or soft tissue/mediastinal emphysema that requires bronchoscopy as soon as the patient's condition permits. "MinIP" reconstructions can serve as a helpful tool in the diagnosis of TBI in CT scans, and in the planning of subsequent diagnostic and therapeutic procedures. There are several ways to ensure the patient's oxygenation up to and including ECMO therapy. Nitric oxide may improve oxygenation in the short term. Although conservative approaches may be attempted in cases of limited injury, lung parenchyma-preserving surgery remains the treatment of choice for TBI. Postoperatively, denervation of the bronchus distal to the repaired area may be an issue, especially in cases of extensive injury to the tracheobronchial tree. Close radiographic and bronchoscopic monitoring is necessary. To ensure optimal recovery, we believe that all TBI patients should receive specialized rehabilitation therapy after discharge from the hospital.

Acknowledgments

Funding: None.

Footnote

Reporting Checklist: The authors have completed the AME Case Series reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-579/rc

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-579/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-579/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013), and was approved by the local ethics committee at the Medical Faculty, University of Leipzig (No. 032/24-ek). All participants consented to the use of their personal data and accompanying images for research purposes by signing the hospital's admission agreement.

References

1. Grewal HS, Dangayach NS, Ahmad U, et al. Treatment of Tracheobronchial Injuries: A Contemporary Review. Chest 2019;155:595-604.
2. Metelmann IB, Oltmans A, Kraemer S. Isolated open bronchus fracture after open die forging. Trauma Case Rep 2021;32:100460.
3. American College of Surgeons Committee on Trauma. Advanced trauma life support : student course manual. American College of Surgeons, Chicago, IL, 2018; 2018.
4. Nelson HP. POSTURAL DRAINAGE OF THE LUNGS. Br Med J 1934;2:251-5.
5. Moore EE, Cogbill TH, Jurkovich GJ, et al. Organ injury scaling: spleen and liver (1994 revision). J Trauma 1995;38:323-4.
6. BURKE JF. Early diagnosis of traumatic rupture of the bronchus. JAMA 1962;181:682-6.
7. Chu CP, Chen PP. Tracheobronchial injury secondary to blunt chest trauma: diagnosis and management. Anaesth Intensive Care 2002;30:145-52.
8. Verkoulen KCHA, van Roozendaal LM, Daemen JHT, et al. Management of tracheobronchial ruptures in blunt chest trauma: pushing the boundaries towards a minimally invasive surgical approach. AME Case Rep 2023;7:21.
9. Kiser AC, O'Brien SM, Detterbeck FC. Blunt tracheobronchial injuries: treatment and outcomes. Ann Thorac Surg 2001;71:2059-65.
10. Zhao Z, Zhang T, Yin X, et al. Update on the diagnosis and treatment of tracheal and bronchial injury. J Thorac Dis 2017;9:E50-6.
11. Jamal Eddine H, Abu Arab W, AlSaleh A, et al. Complex bronchial ruptures in blunt thoracic trauma: management and outcome. Indian J Thorac Cardiovasc Surg 2021;37:311-5.
12. Bagga B, Kumar A, Chahal A, et al. Traumatic Airway Injuries: Role of Imaging. Curr Probl Diagn Radiol 2020;49:48-53.
13. Das KM, Lababidi H, Al Dandan S, et al. Computed

tomography virtual bronchoscopy: normal variants, pitfalls, and spectrum of common and rare pathology. Can Assoc Radiol J 2015;66:58-70.
14. Krauss H. Functional restoration in bronchial rupture. Langenbecks Arch Klin Chir Ver Dtsch Z Chir 1955;282:524-6.
15. Aljehani Y, Aldossary I, AlQatari AA, et al. Blunt Traumatic Tracheobronchial Injury: a Clinical Pathway. Med Arch 2022;76:430-7.
16. Alassal MA, Ibrahim BM, Elsadeck N. Traumatic intrathoracic tracheobronchial injuries: a study of 78 cases. Asian Cardiovasc Thorac Ann 2014;22:816-23.
17. Palade E, Passlick B. Surgery of traumatic tracheal and tracheobronchial injuries. Chirurg 2011;82:141-7.
18. Tracheal Trauma; 2023. Available online: https://www.ncbi.nlm.nih.gov/books/NBK500015/
19. Sauerbruch F. Die Chirurgie der Brustorgane. Berlin, Heidelberg: Springer Berlin Heidelberg; 1928.
20. Kirsh MM, Orringer MB, Behrendt DM, et al. Management of tracheobronchial disruption secondary to nonpenetrating trauma. Ann Thorac Surg 1976;22:93-101.
21. Schibilsky D, Driessen A, White WJ, et al. Traumatic tracheobronchial injuries: incidence and outcome of 136.389 patients derived from the DGU traumaregister. Sci Rep 2020;10:20555.
22. Adhikari NK, Burns KE, Friedrich JO, et al. Effect of nitric oxide on oxygenation and mortality in acute lung injury: systematic review and meta-analysis. BMJ 2007;334:779.
23. Teman NR, Thomas J, Bryner BS, et al. Inhaled nitric oxide to improve oxygenation for safe critical care transport of adults with severe hypoxemia. Am J Crit Care 2015;24:110-7.
24. Aprile V, Korasidis S, Ambrogi MC, et al. Extracorporeal membrane oxygenation in traumatic tracheal injuries: a bold life-saving option. J Thorac Dis 2019;11:2660-3.
25. Bölükbas DA, Tas S. Current and Future Engineering Strategies for ECMO Therapy. Adv Exp Med Biol 2023;1413:313-26.
26. Anile M, Diso D, Rendina EA, et al. Airway anastomosis for lung transplantation. J Thorac Dis 2016;8:S197-203.
27. Yu J, Laohathai S. Case report: video-assisted thoracoscopic repair of right main bronchus transection after blunt chest injury. AME Case Rep 2023;7:17.
28. Schots JP, Vissers YL, Hulsewé KW, et al. Addition of Video-Assisted Thoracoscopic Surgery to the Treatment of Flail Chest. Ann Thorac Surg 2017;103:940-4.
29. Tanaka A, Miyajima M, Obama T, et al. Thoracic surgery for the penetrating lung or tracheal trauma. Kyobu Geka 2006;59:1018-22.
30. Rieth A, Varga E, Kovács T, et al. Contemporary management strategies of blunt tracheobronchial injuries. Injury 2021;52 Suppl 1:S7-S14.
31. van Roozendaal LM, van Gool MH, Sprooten RTM, et al. Surgical treatment of bronchial rupture in blunt chest trauma: a review of literature. J Thorac Dis 2018;10:5576-83.
32. Herve P, Silbert D, Cerrina J, et al. Impairment of bronchial mucociliary clearance in long-term survivors of heart/lung and double-lung transplantation. The Paris-Sud Lung Transplant Group. Chest 1993;103:59-63.
33. Morinari H, Shimada K, Taplin GV, et al. Bronchial mucus after lung autotransplantation in dogs. J Thorac Cardiovasc Surg 1974;67:484-90.
34. Paul A, Marelli D, Shennib H, et al. Mucociliary function in autotransplanted, allotransplanted, and sleeve resected lungs. J Thorac Cardiovasc Surg 1989;98:523-8.
35. Brody JS, Klempfner G, Staum MM, et al. Mucociliary clearance after lung denervation and bronchial transection. J Appl Physiol 1972;32:160-4.
36. Zantah M, Pandya A, Marchetti N, et al. Lung Denervation and Its Effect on Bronchial Responsiveness Following Lung Transplant Surgery. Am J Respir Crit Care Med 2020;201:A2838.
37. Duarte AG, Myers AC. Cough reflex in lung transplant recipients. Lung 2012;190:23-7.
38. Panitch HB. Evaluation of recurrent pneumonia. Pediatr Infect Dis J 2005;24:265-6.
39. Michael Foster W. Mucociliary Function. In: Parent RA, editor. Comparative Biology of the Normal Lung. Academic Press 2015 p. 561-79.
40. Higenbottam T, Jackson M, Woolman P, et al. The cough response to ultrasonically nebulized distilled water in heart-lung transplantation patients. Am Rev Respir Dis 1989;140:58-61.

Cite this article as: Aliev D, Metelmann I, Keller M, Zeidler S, Prasse G, Steinert M, Krämer S. Tracheobronchial injury after blunt thoracic trauma—lessons to learn in diagnosis, treatment, and postoperative care: a case series. J Thorac Dis 2024;16(9):6237-6248. doi: 10.21037/jtd-24-579