MANAGEMENT of tracheal rupture involving the lower third of the trachea is a difficult issue. As suggested by recent literature,1–4 a conservative treatment should be considered in spontaneously breathing patients, to allow the injury to heal. For those requiring mechanical ventilation, this healing is hindered by the presence of the cuff resting on the injury and/or by the positive airway pressure. To circumvent these difficulties, it has been recently proposed to bypass the lesion using a selective bilateral mainstem bronchus intubation with small endotracheal tubes passed through a large tracheostomy.5

With this technique, mechanical ventilation can be performed with low pressure regimen applied to the tracheal rupture, allowing spontaneous healing. However, a small subset of patients with tracheal rupture also has an extension of the rupture into one or both mainstem bronchi. In these cases, especially when they are complicated by acute respiratory distress syndrome, conventional ventilation may be difficult or even impossible. In such patients, jet ventilation allowing ventilation with a deflated cuff and low endobronchial pressure may be an alternative. We report our experience in four patients.

Case 1

A 77-yr-old woman with chronic obstructive pulmonary disease, mitral stenosis, and atrial fibrillation was hospitalized in the cardiology unit for dyspnea exacerbation. In the course of her treatment, a Swan Ganz catheter was inserted, and the patient experienced a cardiac arrest because of a rupture of a branch of the pulmonary artery. After emergency tracheal intubation and cardiopulmonary resuscitation, a tracheal rupture was immediately suspected because of subcutaneous emphysema. A bronchoscopy confirmed the diagnosis. Despite transfusion and amine infusion, the circulatory conditions of the patient remained unstable, and she was transferred to our institution’s intensive care unit (ICU).

On admission, the patient was hypoxemic with a PaO2/FIO2 ratio below 100 (table 1). A repeated bronchoscopy localized a 4-cm tracheal rupture on the posterior side of the trachea ending 1 cm above the carina. A selective embolization of the left inferior lobar pulmonary artery was first performed with a circulatory stabilization.

An emergency thoracotomy was then performed. The repair was impossible, and the trachea was packed with intercostal muscle. Airway control was obtained with jet ventilation throughout the surgery. Jet ventilation was resumed in the ICU with a tracheal catheter introduced through the endotracheal tube whose cuff was kept deflated to maintain a low endotracheal pressure. Using this ventilatory mode, adequate blood gases were obtained. The tracheal rupture reopened on the second day of jet ventilation, and the patient died of hypoxemia.

Case 2

A 67-yr-old woman was admitted to our institution for tracheal rupture management. This patient had required an emergency intubation for hypercapnic chronic obstructive pulmonary disease exacerbation 2 days earlier. Tracheal rupture was diagnosed because of subcutaneous emphysema after intubation. A bronchoscopy performed on admission in our ICU found a large tracheal rupture of the posterior side of the trachea located 1.5 cm above carina. During the first 72 h, the patient was judged not suitable for any surgical intervention because of a severe impairment of oxygenation (table 1). She was ventilated through an endotracheal tube advanced just above the carina. As the cuff of the endotracheal tube rested on the ruptured area and pulmonary atelectasis were recurrent, it was decided to bypass the tracheal rupture. The operation was performed under jet ventilation through a tracheal catheter. A large tracheotomy was performed, and a selective bilateral mainstem bronchus intubation with small endotracheal tubes (external diameter 5.5) was performed as described by Marquette et al.5

This operation allowed protective mechanical ventilation of the acute respiratory distress syndrome and complete healing of the tracheal rupture within 5 days. Adequate blood gases could be obtained on Day 3, and afterward the patient’s recovery was uneventful and she was discharged on Day 20.

Case 3

A 42-yr-old woman was tracheally intubated because of seizures. Because of an aspiration, this patient developed a severe acute respiratory distress syndrome and was transferred to a surgical ICU. Two days after admission, she presented with subcutaneous emphysema, for which she underwent a bronchoscopy. A tracheal rupture was found 1 cm above the carina with a length of 3 or 4 cm. The patient was then transferred to our ICU for further management. On admission, she experienced a severe hypoxemia (table 1).

A median and large tracheotomy was performed, and a selective bilateral mainstem bronchus intubation with small endotracheal tubes (external diameter 5.0) was realized as previously described. An oro-tracheal tube was also positioned to remove secretions from the upper trachea. This procedure was performed under jet ventilation. A controlled ventilatory mode was used in the ICU, allowing the patient to have satisfactory blood gases.

After 10 days of ventilation, selective intubation could be removed, and a nonselective tracheotomy tube was placed. Complete cicatris-
A partial ventilatory mode (biphasic airway pressure ventilation) was used on Day 3 for Patients 2 and 3. Arterial blood gases for the four patients at admission in the intensive care unit 1 and 3 h after the institution of the ventilatory procedure and on Days 1 and 3. The PaCO₂ is reported as its ratio to FIO₂ (P/F). The ventilatory procedure was jet ventilation through the tracheal tube and through the bronchial tube for Patients 1 and 4, respectively. It was a selective bilateral mainstem bronchus intubation for Patients 2 and 3. The ventilatory mode was assisted controlled ventilation on Day 1 for Patients 2, 3, and 4. A partial ventilatory mode (biphasic airway pressure ventilation) was used on Day 3 for Patients 2 and 3. PaCO₂ values are reported in mmHg.

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Arterial blood gases for the four patients at admission in the intensive care unit 1 and 3 h after the institution of the ventilatory procedure and on Days 1 and 3. The PaCO₂ is reported as its ratio to FIO₂ (P/F). The ventilatory procedure was jet ventilation through the tracheal tube and through the bronchial tube for Patients 1 and 4, respectively. It was a selective bilateral mainstem bronchus intubation for Patients 2 and 3. The ventilatory mode was assisted controlled ventilation on Day 1 for Patients 2, 3, and 4. A partial ventilatory mode (biphasic airway pressure ventilation) was used on Day 3 for Patients 2 and 3. PaCO₂ values are reported in mmHg.

A 54-yr-old man was admitted to our ICU for refractory hypoxemia. This patient had a prior esophagectomy with a gastric transposition. Eighteen days after initial surgery, the patient presented with a massive aspiration because of gastric transposition necrosis with tracheal fistula of the right main bronchus 1 cm distal to the carina. A severe acute respiratory distress syndrome developed. The bronchoscopy showed a bronchial rupture on the right main bronchial tract 1 cm distal from the carina. The patient underwent an emergent extraction of the bronchial rupture. During surgery, the tracheal rupture was obliterated using fascia lata. Because of the severe acute respiratory distress syndrome, positive pressure ventilation was mandatory and the surgical repair of the bronchial rupture failed, resulting in a massive air leakage through the bronchial rupture and thoracic drainage. The patient was then transferred to our institution with severe hypoxemia. Arterial blood gases for the four patients at admission in the intensive care unit 1 and 3 h after the institution of the ventilatory procedure and on Days 1 and 3. The PaCO₂ is reported as its ratio to FIO₂ (P/F). The ventilatory procedure was jet ventilation through the tracheal tube and through the bronchial tube for Patients 1 and 4, respectively. It was a selective bilateral mainstem bronchus intubation for Patients 2 and 3. The ventilatory mode was assisted controlled ventilation on Day 1 for Patients 2, 3, and 4. A partial ventilatory mode (biphasic airway pressure ventilation) was used on Day 3 for Patients 2 and 3. PaCO₂ values are reported in mmHg.

**Case 4**

A 54-yr-old man was admitted to our ICU for refractory hypoxemia. This patient had a prior esophagectomy with a gastric transposition. Eighteen days after initial surgery, the patient presented with a massive aspiration because of gastric transposition necrosis with tracheal fistula of the right main bronchus 1 cm distal to the carina. A severe acute respiratory distress syndrome developed. The bronchoscopy showed a bronchial rupture on the right main bronchial tract 1 cm distal from the carina. The patient underwent an emergent extraction of the bronchial rupture. During surgery, the tracheal rupture was obliterated using fascia lata. Because of the severe acute respiratory distress syndrome, positive pressure ventilation was mandatory and the surgical repair of the bronchial rupture failed, resulting in a massive air leakage through the bronchial rupture and thoracic drainage. The patient was then transferred to our institution with severe hypoxemia.

**Comments**

Tracheal rupture is a very rare but potentially devastating complication of tracheal intubation or chest trauma. Besides penetrating or blunt chest trauma, the most common cause of tracheal injury is iatrogenic rupture after tracheal intubation for elective surgery or respiratory failure or after surgical procedures such as esophagectomy. Schönfelder et al. reported 12 patients with iatrogenic tracheobronchial rupture over a 3-yr period after emergency tracheal intubation, whereas no such injury was noted among the 43,773 elective intubations performed over this period. The true incidence of iatrogenic injuries after elective intubation is not clearly known. Reports describe only a few cases. Nevertheless, Borasio et al. estimated an incidence of 1:20,000 during a 7-yr period survey, with tracheal damage being more frequent after double lumen intubation (0.05–0.19%).

Whereas tracheal rupture after chest trauma appears most often as a disruption involving the cartilaginous-membrane junction throughout the bronchial tree, iatrogenic ruptures usually present as a longitudinal laceration of the posterior tracheal membrane. These ruptures seem to occur in conjunction with difficult intubation, use of a stylet, or cuff overinflation. Double lumen intubation may be a major risk factor compared with simple orotracheal intubation. Predominance in women has been documented. Another important risk factor is emergency intubation. Three of our four patients developed tracheal ruptures after emergency intubation. Schneider et al. reported emergency intubation to be present in one third of 29 patients with tracheal rupture. However,
Tracheal rupture may occur after uneventful intubation.\textsuperscript{5–7} A potential mechanism is an endotracheal tube tip caught in a fold of a flaccid posterior tracheal membrane while advancing it.\textsuperscript{5} Tracheobronchial injury after surgery is mainly observed after subtotal esophagectomy, as in Patient 4. It is a rare event, but in this case, the injury occurs mainly proximal to the carina or in the main bronchi.\textsuperscript{14} The rupture is usually intraoperatively managed effectively by surgical closure with pericardium or pleura and apposition of the gastric tube. Postoperative tracheobronchial injury associated with an ischemic gastric conduit needs further surgical exploration and even resection of the gastric tube.\textsuperscript{15}

An early and important finding is subcutaneous emphysema of the neck and face after tracheal intubation and positive pressure ventilation.\textsuperscript{1,4,5} Other frequent signs are pneumothorax and mediastinal emphysema.\textsuperscript{5} Respiratory failure may occur because of the underlying condition or because of the tracheal rupture.\textsuperscript{5} It is important to identify this condition quickly because management is dramatically different between patients with or without respiratory failure.\textsuperscript{5} Some patients may remain asymptomatic for prolonged periods.\textsuperscript{16}

Diagnosis can be confirmed by radiologic findings that show pneumothorax and mediastinal or subcutaneous emphysema.\textsuperscript{5,12} These findings usually are evident on chest radiographs, although computed tomography can be particularly helpful to identify mediastinal emphysema and paratracheal air.\textsuperscript{17,18} Recent developments of spiral computed tomography permit virtual bronchoscopy, a technique to identify traumatic tracheal injury.\textsuperscript{19} However, this technique has never been evaluated iniatrogenic tracheal ruptures. Chen et al. reported that computed tomography is inferior to bronchoscopy, which remains the gold standard for tracheal rupture diagnosis.\textsuperscript{17}

Surgical management has been traditionally proposed as the therapeutic approach for tracheal rupture.\textsuperscript{20} However, there is currently a growing body of evidence showing that tracheal rupture can be managed with conservative treatment. Such treatment was initially limited to patients with small tears less than 2 cm in length, a delayed diagnosis, or patients with poor clinical conditions.\textsuperscript{21} Because of the high mortality of surgical treatment,\textsuperscript{22} nonoperative treatment has been further extended to patients with absence of esophageal injury, minimal mediastinal air collection, nonprogressive mediastinal or subcutaneous emphysema, and the absence of sepsis. Finally, a recent report concluded that conservative nonoperative treatment should be considered for tracheal rupture in patients breathing spontaneously or with a planned extubation within the first 24 h.\textsuperscript{5} Indeed, Conti et al. reported excellent results of conservative management regardless of the size and location of the tracheal rupture or the delay from extubation to diagnosis.\textsuperscript{5} However, management of patients with severe respiratory failure requiring mechanical ventilation remained a more difficult issue.

Indeed, the presence of an endotracheal tube with an inflated cuff and positive airway pressure is likely to impair the healing of the tracheal injury. The location of the tracheal injury is a major issue for the management of these patients. When the tracheal rupture is proximal (i.e., first or second third of the trachea), bridging of the lesion may be possible and should be preferred.\textsuperscript{5,23,24} The patient is then mechanically ventilated through an endotracheal tube placed distally to the injury. In these conditions, the healing of the tracheal rupture is not hindered by the tracheal cuff or positive airway pressure. This strategy fails when the tracheal rupture is located on the lower third of the trachea or involves a bronchial mainstem. Jet ventilation through the endotracheal tube with a deflated cuff could allow the patient to be ventilated in such cases. Indeed, this method was used during the tracheotomy procedure to avoid further impairment of hypoxemia in patients who were already hypoxicemic. Nevertheless, the cases of Patients 1 and 4 illustrate that even jet ventilation through an endotracheal or endobronchial tube with a deflated cuff and low endoluminal pressure do not allow tracheobronchial healing. It may be that even a low tracheal or bronchial pressure maintained some gas flow through the injury, preventing any healing. This failure of jet ventilation prompted us to adopt an alternative strategy for Patients 2 and 3 with low tracheal rupture, following the suggestions of Marquette et al.\textsuperscript{5} A selective bilateral mainstem bronchus intubations with high-volume/low-pressureuffed endotracheal tubes were performed through large tracheotomies.\textsuperscript{25} The tracheotomies were required because endotracheal tubes were too short to be placed endobronchially via orotracheal intubation.\textsuperscript{26} During these procedures, jet ventilation was performed with jet catheters inserted beyond the tracheal openings to ventilate the patients. The patients were then ventilated according to a protective ventilatory protocol for their acute respiratory distress syndrome. Meanwhile, the tracheal rupture was put at rest and therefore could heal. For Patient 4, the situation was a little bit more complicated as the tracheal rupture involved the right mainstem bronchus. Meanwhile, an attempt to repair the tracheal fistula was unsuccessful, and the patient was transferred to our ICU for management. We performed a selective bilateral mainstem bronchus intubation under jet ventilation during tracheotomy as before. However, the right tube did not bypass the bronchial injury because it was too close to the right superior lobar bronchus. The patient was estimated to be too critically ill to undergo additional surgery, and we chose to ventilate the patient through the two endobronchial tubes. To minimize the endobronchial pressure, we used jet ventilation on the right lung, whereas the left lung was ventilated in a conventional manner. This ventilatory regimen was initially
beneficial to the arterial blood gases, but the leak through the right chest tube persisted, indicating a lack of bronchial injury healing. Unfortunately, the patient died 10 days later from a nonventilatory cause. Retrospectively, conventional ventilation on the right side at the expense of upper right lobe ventilation could possibly have enhanced the bronchial healing and more rapid ventilatory weaning.

Based on recent publications and our experience, nonoperative management of tracheal rupture in patients requiring mechanical ventilation should be considered. The management of proximal and mild tracheal rupture may be performed by simply bridging the lesion. Ideally, the tube should be placed with the help of fiberoscopy to prevent selective intubation. For patients with lower tracheal rupture, the situation is more difficult. If the rupture does not involve one of the mainstem bronchi, a large tracheotomy could be performed to permit bilateral selective intubations, allowing the lungs to be ventilated and the tracheal injury to heal. However, if the tracheal rupture involves one of the mainstem bronchi, the situation is even more complicated. To heal, the tracheobronchial rupture should be kept at rest with no pressure applied. As shown in Patient 4, even low pressure (<10 cm H₂O) that could be obtained with jet ventilation may be too much to allow healing. One alternative strategy is to inflate a tube cuff distal to the rupture. For the left mainstem bronchus, this approach may only be possible if the tracheal rupture is proximal. However, this could not be performed for the right mainstem bronchus because of the proximity of the right superior lobar bronchus.

In conclusion, management of tracheal rupture associated with respiratory failure is a difficult issue. Simple bridging of upper tracheal injuries with an endotracheal tube placed distal to the lesion may be helpful. When tracheal rupture involves the lower third of the trachea, carina, or left mainstem bronchus, a selective bilateral mainstem bronchus intubation via a large tracheotomy should be considered. When tracheal rupture is located on the right mainstem bronchus, the situation is potentially critical because of the proximity of the right superior lobar bronchus.

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Unsuccessful Cardiopulmonary Resuscitation during Neurosurgery: Is the Supine Position Always Optimal?

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NEUROSURGICAL procedures are often performed in the prone, sitting, or lateral position for improved surgical access. Cardiopulmonary arrest while in such a position creates a challenge for both the anesthesiologist and surgeon. We present two cases of cardiopulmonary arrest and unsuccessful attempts at resuscitation after repositioning supine. In both cases, the surgical site of bleeding became inaccessible with repositioning, leading to the question of whether prone resuscitation would have provided a better alternative.

Case Reports

Case 1

A 21-yr-old woman with a medical history significant for neurofibromatosis type 2 and multiple neurofibromas presented with a right jugular foramen tumor and was scheduled to have a skullbase craniotomy for tumor debulking. After induction of anesthesia, the patient was placed in a left lateral decubitus position. During the surgical procedure, the sigmoid sinus was disrupted, leading to significant blood loss and hypotension. Blood products were delivered via a rapid infusion device and vasopressors were administered. Attempts to gain further access to the bleeding site resulted in two additional small lacerations of the transverse-sigmoid junction. Attempts to suture these and ligate the sigmoid sinus were unsuccessful. Despite the compromised sinus, there was no evidence of venous air embolism, as judged by end-tidal carbon dioxide and peak inspiratory pressures. The patient’s hemodynamics continued to deteriorate, and she was placed in the supine position for cardiopulmonary resuscitation (CPR). After turning the patient to the supine position, the surgical site became inaccessible and the patient continued to bleed briskly from the wounds. The patient developed pulseless electrical activity and resuscitation efforts were unsuccessful.

Case 2

A 69-yr-old woman with renal cell carcinoma that metastasized to the lumbar spine and encroached on the neural foramen presented for lumbar and posterior lumbar corpectomy and fusion. Her surgical history was significant for nephrectomy, and she had undergone embolization of the mass 1 d before surgery. After induction of anesthe-sia, the patient was positioned prone, and the posterior portion of the planned procedure was uneventful. The patient was then placed in a lateral park-bench position for the anterior fusion. Upon scraping of the second lumbar endplate, a small tear of a contralateral segmental vessel off the aorta occurred. Blood loss was significant and the patient was treated with fluids, blood products, and vasopressors. The aorta was cross-clamped and the vessel repaired. After repair, the patient’s hemodynamics stabilized and the surgical field remained dry. Approximately 10 min later, multiple sites of oozing were noted from the retroperitoneal fat, from the site of vertebral corpectomy and muscle. The patient’s blood pressure began to decrease and required ongoing volume resuscitation, a norepinephrine infusion, and a 50-μg bolus of epinephrine. As her blood pressure improved, the bleeding increased and the patient developed pulseless electrical activity arrest. The wounds were packed to tamponade the bleeding, and the patient was positioned supine for CPR. Access to the source of bleeding was impossible in the supine position—during resuscitation, blood was noted to be exiting the surgical site. After 20 min of unsuccessful CPR, resuscitation efforts were ceased.

Discussion

Neurosurgical procedures often involve various nonsupine positions, including prone, sitting, and lateral decubitus. Although intraoperative cardiac arrest is fortunately an uncommon event, when it occurs with the patient in a position other than supine, access to a bleeding operative site can be difficult or impossible. In addition, an open wound, time required to reposition the patient, and an unstable spine may lead to a deleterious outcome. Alternative methods for CPR may therefore be desirable.

Cardiac resuscitation was first described by Kouwenhoven et al. in 1960 and has remained essentially unchanged for more than 45 yr. 1 It was originally thought that blood circulates based on direct compression of the heart against the vertebral column. Rudikoff et al. challenged this theory by demonstrating that alterations in intrathoracic pressure lead to blood flow and direct cardiac compression is not required. 2 This “thoracic pump mechanism” suggests that the heart is merely a conduit for blood flow. In 1989, McNeil 3 proposed prone CPR as an alternative to supine CPR for out-of-hospital arrests to address problems with traditional CPR. Such problems include reluctance of providers to perform mouth-to-mouth ventilation, risk of gastric distention and aspiration, and difficulty in learning and retention of the procedure. 4

Prone resuscitation by reverse precordial compressions was first described in two case reports by Sun et al. in 1992. 5 The first procedure was a posterior fossa craniotomy in which the transverse sinus was torn; the
second was a cervical spine procedure in which an obstructed endotracheal tube led to arrest. The resuscitative method involved placing the left clenched fist under the sternum while compressing the mid-thoracic spine with the right hand. This produced arterial systolic pressures of 160 mmHg in one case and 200 mmHg in another. In both cases, a life-sustaining rhythm and blood pressure were obtained within 6 min. In 1994, Tobias et al. described a modified technique during spinal surgery with an open wound. In this case, the surgeon compressed the thoracic cage with a palm placed over the scapula on each side of the spinal wound. The patient was on a frame that supported his anterior thorax so counterpressure on the sternum was not necessary. Systolic blood pressures of 80-90 mmHg were noted, and the patient was successfully resuscitated after 7 min of asystole.

Based on McNeil’s description of CPR in the prone position and the case reports of intraoperative prone CPR, Mazer et al. performed a pilot study of CPR in the prone position. The study compared traditional CPR and reverse CPR with the primary endpoint of systolic blood pressure. They revealed that reverse CPR dramatically improved systolic blood pressure and mean arterial pressure (mean improvements 23 ± 14 mmHg and 14 ± 11 mmHg, respectively). Brown et al. performed a systematic review of 22 cases of intubated hospital patients who received prone CPR, 10 of whom survived.

The 2005 American Heart Association Guidelines for CPR and Emergency Cardiovascular Care recommend that prone CPR be considered when the patient cannot be placed in the supine position, particularly for the hospitalized patient with an advanced airway. The recent patients at our institution were positioned lateral decubitus at the time of cardiopulmonary arrest; we have found no reports describing CPR in the lateral position. In the cases we describe, placing the patient in the prone versus the supine position for resuscitation may have provided improved access to the surgical site and at least preserved the potential for surgical correction of the problem. Even in arrests not involving exsanguination, the studies of Mazer et al. and Wei et al. suggest that prone CPR may be advantageous in generating higher blood pressures compared with the supine position.

These cases suggest that the prone position should be considered as the optimal choice for CPR in certain limited circumstances, even if the supine position is achievable. As such, further research on prone CPR is warranted.

References