Bilateral Tension Pneumothorax Following Equipment Improvisation

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This case report describes an unexpected event that took place as a result of using improvised equipment. The patient, a 16-year-old female undergoing complex oral surgery, suffered bilateral pneumothorax following the improper use of an airway support device. During the immediate postoperative period with the patient still intubated, oxygen tubing was attached to a right angle elbow connector with the port closed and 10 L/minute oxygen flow was administered to the patient in a manner that did not allow the patient to exhale. Within seconds, pneumothorax was apparent as the patient’s vital signs deteriorated, visible swelling was noted in the shoulders and neck, and there was an absence of breath sounds on auscultation. This case study has application beyond the immediate discussion of bilateral pneumothorax, serving as a caution about the unintended consequences of equipment improvisation. In addition to highlighting the hazards of providing patient care with a non-standard device, this study also provides a powerful example of the human factors that can contribute to medical errors in the healthcare setting.

Keywords: Equipment improvisation, human factors, normalization of deviance pneumothorax, right angle connector.

A 16-year-old, 162 cm, 86-kg female with a history of fibromyalgia and temporomandibular joint pain underwent bilateral sagittal ramus osteotomies with rigid fixation, total maxillary osteotomy with graft, and advance-ment genioplasty with turbinectomy under general anesthesia. Preoperatively, the patient received midazolam 2 mg, dexamethasone 8 mg, and a 900 mg clindamycin drip infused 1 hour prior to incision. Following preoxygenation, the patient was induced with propofol 250 mg, 1 mg midazolam, and 100 µg fentanyl. Vecuronium 10 mg and xylocaine 30 mg were administered prior to placing a 7.0 nasoendotracheal tube x 1 attempt. Following verification of placement by end-tidal CO2 and bilateral breath sounds, the tube was secured, eyes taped, and the anesthetic was maintained with isoflurane, oxygen, air and nitrous oxide, fentanyl, and vecuronium. Metoclopramide 10 mg was administered shortly after induction. The patient’s intraoperative course was uneventful with stable vital signs and minimal blood loss. Dexamethasone 8 mg and ondansetron 4 mg were administered during the case. Hydromorphone 0.5 mg and midazolam 2 mg were given near the end of the anesthetic. The muscle relaxant was reversed at the end of the case with neostigmine 4 mg and glycopyrrolate, and the patient was somnolent with spontaneous respirations and good oxygen saturation. The procedure lasted approximately 7.5 hours.

The certified registered nurse anesthetists (CRNA) called for a bed in the main recovery room but the postanesthesia care unit (PACU) was full. It was a busy surgical day and operating rooms were at a premium so the team needed to vacate the operating room rather than remain until the patient was more fully awake.

The CRNA clinical coordinator instructed the team to take the patient to the children’s surgical center recovery room. This unit is located a short walk down the hallway from the main operating room area and is commonly used for low acuity pediatric outpatient surgery cases, such as tonsillectomies and hernia repairs.

The patient was transported to the children’s center PACU via stretcher with the nasoendotracheal tube in place and spontaneous respirations. Oxygen was administered en route. As was the custom at this facility, the right angle elbow connector from the breathing circuit was left attached to the NET for postoperative oxygen administration.

When the patient arrived to the pediatric outpatient surgery recovery room, the exhaust port on the right angle elbow connector was closed and the PACU nurse placed the oxygen tubing tightly within the lumen of the connector as she set the oxygen flow meter at 10 L/minute. Upon admission to the PACU, the modified Aldrete score was 9 with a blood pressure of 116/77, pulse 103, and respirations 16. The SaO2 was 100 and the EKG showed sinus tachycardia.

While the report was being given, the patient was noted to have swelling in the upper chest and face. Cyanosis developed rapidly with concomitant tachycardia, hypotension, and decreasing SaO2. Chest auscultation revealed minimal or absent breath sounds and expanding
subcutaneous emphysema was noted throughout the patient's upper chest and neck.

The endotracheal tube was quickly disconnected from the curved connector oxygen source and a loud pressure release sound was noted. A STAT chest x-ray was obtained and surgery was consulted. The chest x-ray identified bilateral pneumothorax. The surgical resident placed bilateral chest tubes and again an audible air pressure release was noted upon insertion of the tubes.

The patient was ventilated with 100% O₂, placed on a ventilator, and medicated for comfort. Her vital signs returned to baseline. She was transferred to the pediatric intensive care unit. The following day the patient was extubated and the chest tubes were removed. The event was fully disclosed to the patient and her family and she was discharged from the hospital on the 6th postoperative day without further complications.

Discussion

The scope of practice of CRNAs demands detailed expertise and airway management is of vital concern. Nonetheless, anesthesia providers continue to experience challenges within this clinical realm, as over 37% of liability claims in the American Society of Anesthesiologists (ASA) Closed Claims Project database are due to issues related to airway management. In their early and precedent setting work in anesthesia safety, Cooper et al identified airway-related occurrences as contributing to the highest number of critical incidents in anesthesia practice.

Oxygen is commonly delivered from a central hospital supply. Through the use of metered down-regulating devices, the high pressure (50 psi) hospital source is reduced to low pressure variable flow delivered within physiologic ranges, generally at a flow rate of 1–15 L/minute.

- **Pneumothorax as a Critical Incident.** Barotrauma and bilateral pneumothorax are serious physiologic abnormalities that can result in significant morbidity and even death. In the anesthesia literature, these complications are described most commonly in association with jet ventilation and rarely seen in the course of routine recovery from general anesthesia. It is unusual for cases describing pulmonary barotrauma to appear in conjunction with low-pressure oxygen insufflation alone, but when it occurs, it is generally due to problems with egress of air from the lungs.

Anesthesia-associated pneumothorax have also been known to occur following central venous pressure line placement, right mainstem bronchus intubation, regional nerve block, or surgery in close proximity to the pleural cavity, such as nephrectomy. Other causes of pneumothorax include injury during chest trauma or with diagnostic procedures, such as pleurocentesis or laparoscopy. Spontaneous pneumothorax may also occur in association with chronic obstructive pulmonary disease or occasionally in healthy young adults.

Pulmonary barotrauma may occur with the rapid or excessive application of positive pressure to the tracheobronchial tree and is damaging to the respiratory structures. Volutrauma is a distinct entity referring to overdilatation of alveoli. Initially well tolerated, this increase in volume eventually leads to an increase in pressure, culminating in barotrauma. The subsequent alveolar injury results in a tension pneumothorax.

While high-pressure jet ventilation may cause barotrauma by direct damage to tissues, low-flow gas insufflation may first cause volutrauma which can lead to barotrauma. In this case study, the continuous gas insufflation was particularly hazardous because the closed cap on the circuit elbow coupled with the tight fit of the oxygen tubing prevented the egress of exhaled gas. At 10 L/min flow, rapid breath stacking and auto-PEEP occurred. The inspired gas volume exceeded the exhaled gas volume with resultant volutrauma damaging lung parenchyma. This injury led to barotrauma and bilateral pneumothorax within seconds.

Gaba identifies several critical strategies for the recognition and treatment of pneumothorax, including prompt diagnosis by chest auscultation, assessment of tracheal deviation (unilateral pneumothorax, especially tension pneumothorax), and recognition of soft tissue swelling and crepitus. Simultaneous administration of 100% oxygen, vasopressors, insertion of a large-bore IV catheter into the pleural space at the intersection of the second intercostal space and the mid-clavicular line are essential strategies while the responsible surgeon is notified. These immediate interventions are life-saving until a chest tube can be placed. In the event of cardiovascular collapse, vasopressors may be required.

- **Human Factors.** The Swiss Cheese Model (Figure 1) is a familiar failure construct in healthcare depicting layers of defense in which, on occasion, the holes in the defenses line up and a latent error turns into a bad patient outcome. This case study describes human factors that together resulted in swift deterioration of a young healthy patient and avoidable morbidity. Even though the critical event was perceived as sudden in onset and rapid in development, it is clear that the evolution of this crisis emerged from preexisting factors.

In order to achieve a root cause understanding, this case will be analyzed based on a human factors approach as well as crew resource management principles. Fletcher proposes the acronym ERR WATCH as an effective tool for CRNAs to remember and interpret these concepts. These ERR WATCH principles will be used to guide our case discussion (Table 1).

- **Environment.** The environment consists of people, location, and things that come together in the care of the patient.
A key predisposing factor in this case was the presence of a latent error that had been dormant in the system for a long time. It was customary at this hospital to transport intubated patients to the recovery room with the curved connector from the anesthesia breathing circuit attached to the endotracheal tube. The port cap for end-tidal CO₂ monitoring during anesthetic administration was always left open or removed. In the PACU, green oxygen tubing was pushed into the open end of the curved connector and the other end was connected to the oxygen flow meter (Figure 2).

This improvised equipment was referred to as a “t-piece” by the staff. In contrast, a traditional t-piece is a plastic “t” with a plastic corrugated tube attached to one side and the other side attached to a humidified jar that is connected to the oxygen source (Figure 3). Exhaled air flows freely out of the corrugated tubing.

Lacking correct equipment in a hospital is not uncommon. The improvised t-piece in this case study can be viewed as a concrete example of the “normalization of deviance” described by Vaughan in reference to the Challenger disaster. In the case of both rocket science and hospital procedure, production pressure and the institutional goal to reduce costs become part of departmental culture. The improvised t-piece in this case study had been in place for at least a decade without apparent harm to patients; thus, the continued successful outcome gave the impression of low risk to patients and clever cost-saving ingenuity. The perceived risk of using this invention dissipated with the gradual acceptance of the abnormal as normal.

In human beings, performance is not constant; rather, it varies because it is affected by many factors, such as fatigue, stress, distraction, and production pressure. These realities in the operating room environment may have played a role in causing the human error of leaving the port closed on the curved connector (Figure 4).

Clinicians do not consciously sacrifice safety to cut costs or get the next case completed faster. Rather, production pressure and resource constraints become institutionalized in operating room culture. Although in retrospect it is easy to see that using this piece of equipment for a purpose for which it was not designed was a bad decision, the equipment was used successfully in this manner for years without patient harm and became an established norm. Through repeated use, acceptance persisted until the combination of this latent error and human factors led to a critical incident.

Table 1. ERR WATCH
Adapted with permission.

Fletcher’s ERR WATCH principles
Know your environment
Use your resources appropriately
Reevaluate frequently
Workload
Attention allocation
Teamwork
Communication
Call for help early

Figure 1. Swiss Cheese Model (Reason)

Figure 2. Right Angle Connector with Port Open and Oxygen Tubing Inserted

Figure 3. Traditional T-piece with Oxygen Tubing Attached

Figure 4. Human Error in the Operating Room Environment

Table 1. ERR WATCH
Adapted with permission.
Other environmental factors leading to this event were the people and location of the care. The Registered Nurse (RN) and the CRNA involved in the care of the patient had not worked together before. The recovery room location was unexpected and somewhat unfamiliar to the CRNA; she was directed at the end of the case to change the postoperative plan and proceed to the pediatric PACU rather than to the PACU adjacent to the main operating room. This last-minute change in plans was a distraction that took the CRNA's attention away from the routine action of removing the cap on the curved connector. Similarly, the PACU RN involved in the case felt that she was not familiar with caring for adult-like patients undergoing adult procedures. This insecurity was partially responsible for the nurse's decision not to question the airway equipment set up.

- **Resources.** Effective management of critical incidents when they occur is the key to preventing evolution to an adverse outcome. Resource management is an essential skill for nurse anesthetists. Within the context of detecting and correcting problems in the perioperative environment, the resources available to the CRNA include self, other personnel, equipment, cognitive aids, and external resources.

In this case, the CRNA detected the problem and deployed critical resources to intervene before it progressed to a potentially fatal outcome. While giving report, the CRNA used parallel processing (giving report and observing the patient at the same time). The anesthetist's decision making at this point involved multiple levels of activity (Table 2).12

With the possible exception of inserting a large-bore intravenous catheter into the pleural space to immediately treat the pneumothorax, the handling of this event was successful based on universally accepted algorithms and abstract reasoning for an optimum result. The chest x-ray confirmed the clinical diagnosis but was not essential in an unstable patient.

When the CRNA detected that something was wrong with the patient, fixation errors13 (Table 3) were not a factor as the CRNA moved immediately to active resource management. This is consistent with the preconditioned response of an expert vs a novice anesthetist.

- **Reevaluate.** Successful dynamic problem solving requires frequent reevaluation because the available cues do not always identify a problem. Had the CRNA reevaluated the nasoendotracheal tube and the connector during transport of the patient, the problem may have been detected sooner. Prior to connecting the oxygen is a good time to reevaluate the entire oxygen delivery system for patency and correctness.

After the critical event occurred, frequent reevaluation of the patient took place, including repeated auscultation of the chest, rechecking vital signs, obtaining pertinent lab
results, and reevaluation of oxygenation and perfusion.

- **Workload.** When a crisis occurs, the CRNA must call for help and distribute the workload across all of the available resources. Tasks must be assigned based on the skills of the individuals. In this case, there was no overload or failure as a team. The team members—including surgeon, anesthesiologist, surgical resident, CRNA, RN, and radiation technologist—worked in a coordinated fashion and performed correct and timely interventions successfully.

- **Attention.** Attention allocation is a dynamic process in which tasks must continually be reprioritized. Although this cascade of events was set in motion by a lack of attention to an important detail (capped port on curved connector), team members maintained vigilant assessment of the patient throughout the myriad of tasks occupying their attention.

- **Teamwork.** Good teamwork is never as important as it is in the midst of a patient crisis; yet, it is frequently at that point where teamwork breaks down. In this case study, the team worked well together. They concentrated on what was right for the patient rather than what had happened or whose fault it was. Due to the atmosphere of open exchange, everyone participated in reassessing the patient and acting on the information in a concerted manner.

- **Communication.** Good communication is a complex skill that is required for highly effective teamwork. In healthcare as in aviation, the social structure of communication may impair the conveyance of clear meaning. For example, an individual from a social level considered subordinate may hesitate to mention a concern or to correct someone considered to be their superior.

Nursing has a long history of not speaking up in relation to physicians, but this case describes the reluctance of an RN to question an advanced practice nurse—the CRNA. After the fact, the PACU RN reported that when the CRNA brought the patient to the pediatric PACU she thought it odd that the port on the connector was closed but she hesitated to bring it up because she assumed that the CRNA knew more than she did and she did not want to appear foolish. The RN had not previously worked with the CRNA and said that she felt hesitant to question the CRNA since she worried that the CRNA would not respond positively to her questions.

**Conclusion**

This case study reports an unexpected event in the course of treating a patient and the resultant morbidity as a result of latent errors and human factors. A review such as this serves to draw attention to these conditions and assist clinicians who may encounter similar circum-

**REFERENCES**


**AUTHORS**

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