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Mechanical Ventilation Strategies in Massive Chest Trauma

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In the realm of trauma and critical care, intensivists are challenged in the management of patients demonstrating respiratory and hemodynamic instability after sustaining massive chest trauma. A fundamental goal of critical care management is to avoid hypoxia and hypoventilation, the two main causes of mortality in the acute period following trauma. For most chest trauma patients, endotracheal intubation and chest tube insertion are the mainstays of treatment; however, a subset of these life-threatening injuries will require a more specialized approach.

A good trauma history and physical examination are essential. Elucidating the mechanism of injury, combined with assessment of the respiratory and hemodynamic status of the patient, can lead to prompt and appropriate intervention. Hemodynamic instability or a high output of bloody chest tube drainage may require other surgical intervention, such as a thoracotomy for pericardial tamponade or uncontrolled hemorrhage. In some cases, a laparotomy is required (eg, diaphragmatic rupture) [1].

In a recent multicenter review, Karmy-Jones and colleagues [2] noted a 40% incidence of emergent thoracotomy for penetrating injury, versus 17% incidence of emergent thoracotomy for blunt chest injury. Their reported 31% incidence of patients requiring pulmonary parenchymal procedure at thoracotomy was higher than the 20% rate generally reported in the literature [3–6]. On the other hand, the mortality following blunt trauma (68%) was significantly greater than that following penetrating injury (19%). The difference in mechanism-based mortality is primarily because of more severe systemic injuries commonly seen with blunt trauma as opposed to penetrating trauma [2].

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Pathophysiology of lung injury caused by trauma

The patient's mechanism of injury is important, because penetrating and blunt injuries have different clinical courses and sequelae. Blunt injuries are common and are primarily managed nonoperatively, whereas penetrating injuries tend to require operative intervention.

The pathophysiology behind the injury seen with massive chest trauma (blunt or penetrating) is a two-hit process: (1) direct parenchymal damage, and (2) alveolocapillary changes caused by systemic inflammation. Lung injury begins with the direct transmission of energy or lacerative traumatic injury resulting in pulmonary contusion, hemorrhage, and rupture.

In many cases, deterioration of lung function is caused by the systemic inflammatory effects of injury. Eventually, acute lung injury (ALI) and adult respiratory distress syndrome (ARDS) can ensue. Following trauma, pulmonary dysfunction is associated with increased vascular permeability in remote organs [7]. Consequently, extravascular fluid sequestration leads to third-spacing and contributes to hemodynamic instability. Excessive bronchial secretions can lead to lobar collapse, hypoxemia, decreased compliance, and postobstructive airway infection. Half of these patients will develop pneumonia [8]. All of these pathophysiologic events result in ventilation/perfusion mismatch, which compromises oxygen absorption in the lungs and subsequent oxygen delivery to vital organs.

Supportive management

The mainstay of most clinical management in chest trauma is supportive care to control and contain the primary lung injury. The goal is to minimize the development of systemic inflammatory response syndrome (SIRS) and subsequent ALI/ARDS. Bilkovski and colleagues [9] suggested that early goal-directed therapy, such as avoidance of profound shock or, conversely, avoidance of excessive fluid overload, should take place by means of a continuous process of hemodynamic monitoring for adequate circulatory resuscitation. This can be achieved by a judicious balance of crystalloids and—once the initial resuscitation is completed—oncotic support, diuretics and inotropes.

Thoracotomy for severe blunt chest injury

One indication of a need for operative intervention is an uncontrolled hemorrhage or air leak following chest trauma. In an unstable patient with the triad of hypothermia, acidosis, and coagulopathy, however, a damage control thoracotomy (DCT) may be the only option [10–13]. Massive hemoptysis caused by bronchial vessel rupture/laceration, severe pulmonary contusion, tracheobronchial injury, massive air leak (MAL), and bronchopleural fistula (BPF) must be corrected. Temporary measures to control and contain bleeding either by bronchoscopic endobronchial balloon tamponade followed with bronchial artery embolization [14] or by operative stapler tractotomy can be life-saving [2]. As soon as the patient is hemodynamically stabilized, a CT scan of the chest is of paramount importance as an adjunct to diagnosis and to provide guidance for further management.

Role of nonthoracic injuries

Long bone fractures complicate pulmonary management in that they prevent the mobilization of a patient that is required for good pulmonary toilet. Some literature suggests that early temporary stabilization of a fracture (eg, external fixation or damage-control orthopedics) will allow improved pulmonary toileting while deferring final fixation to when the patient is recovered. After temporary immobilization of long bone fractures, definitive fracture fixation that is delayed 2 to 3 days after injury has been shown to reduce the incidence of post-traumatic ARDS [15,16].

Combined severe abdominal and thoracic trauma represents a major risk factor for early-onset pneumonia [17]. Mechanical ventilation administered during the first days after trauma seems to reduce the risk of early-onset pneumonia. Mechanical ventilatory support lasting more than 5 days, however, is associated with an increased risk of late-onset pneumonia [17]. Rigorous pulmonary toileting, including endotracheal suctioning and bronchoscopy as necessary, is required to reduce the incidence of late-onset pneumonia. Because it is difficult to distinguish between lung injury and lung infection, either clinically or by imaging, bronchioalveolar lavage (BAL) sampling can help to limit the use of antibiotics and tailor the spectrum of antibiotics [18].

In any patient with an anticipated ventilatory duration over 2 weeks, consideration of performing a tracheostomy should be done early as an adjunct to pulmonary toilet [19]. Additional adjuncts to pulmonary toileting include the management and provision of adequate sedation and analgesia, which should include a scheduled reduction of sedation to allow patient cooperation with pulmonary toilet efforts. Epidural anesthesia/analgesia for regional block has been shown to have a significant impact on improving pulmonary mechanics and modifying the immune response in patients with severe chest injury [20].

Independent lung ventilation

Independent lung ventilation (ILV) is a method of mechanical ventilation in which the right lung and left lung are managed independently, either by anatomical or physiological separation. ILV can either be one-lung ILV (OL-ILV) or two-lung ILV (TL-ILV). Of note, the usage of ILV is only possible because of the development of the double-lumen endotracheal tube DL-ETT.

Evolution of the double-lumen endotracheal tube

The DL-ETT first was introduced in 1949. The first tube was introduced by Carlen, which was a DL tube made up of firm red rubber, with a carinal hook to secure the tube, two separate cuffs (tracheal and bronchial), and a side hole between the cuffs. One lumen ends distally and the other lumen opens on the side hole. The Robertshaw tube is a modification of Carlen's tube with basically the same framework but without the carinal hook. The design has both left- and right-sided variants, where the bronchial cuff of the right-sided tube is slotted for right upper lobe ventilation (Box 1).

Currently, DL-ETT is made of polyvinyl chloride. It is softer, more flexible, and less irritating, thus reducing iatrogenic trauma to the tracheobronchial area. The tubes have larger internal-to-external diameter ratio, allowing more space for diagnostic and therapeutic intervention. The tube is transparent, allowing bronchoscopic visualization of the blue endobronchial cuff for adequate inflation and evaluation of the tracheobronchial mucosa. The cuffs are a high-volume low-pressure design, reducing the incidence of injury [24].

The concept of ILV first arose in 1931 when it was used for the practice of anesthesia during thoracic surgery. Subsequent to this, its usage spread in 1976 within an intensive care setting [30,31] and was specifically mentioned in 1981 for chest trauma [32].

The first noted use of ILV in chest trauma was in a 53 year old female who developed a unilateral ''white lung'' three weeks after injury. This was eventually diagnosed as an intra-parenchymal pulmonary hematoma. ILV was used with high-frequency positive-pressure ventilation within the diseased lung [32]. Although this was the first reported usage of ILV in a trauma patient, it was not used in the acute stage of injury (Table 1) [27,32–48].

The indications for ILV use in critical care for acute respiratory failure are defined poorly as compared with its use in thoracic anesthesia [49]. There is some evidence that ILV is an excellent option as a rescue ventilator strategy in critical care when conventional techniques fail, specifically in the case of a unilateral chest injury. One established criterion for ILV use in asymmetric lung injury is the demonstration of the effects of paradoxical PEEP: (1) hyperinflation of the normal lung, (2) a fall in PaO_2, and (3) an increase in shunting due to redistribution of blood flow [50,51].

One-lung–independent lung ventilation

OL-ILV is a technique in which the patient undergoes ventilation of one lung while the other main or subsegmental bronchus is blocked

Box 1. Double-lumen endotracheal tube insertion technique and maintenance

Choose which mainstem bronchus to cannulate

Select the size of the DL-ETT appropriate for the patient. For adults of varying weight, Fr# 37, 39 and 41 are recommended [21].

Route of insertion
Transoral
Transtracheal [22]

Method of guided insertion [23]
Laryngoscopic
Retrograde wire
Flexible bronchoscopy

Confirm proper positioning [24,25]
Auscultation
Radiography
Flexible bronchoscopy

Check air leak around bronchial cuff to ensure functional separation [26].
Water bubble technique
Balloon technique

Dual monitoring to detect tube displacement [27–29]
Noninvasive
- End tidal capnography
- Peak and plateau pressure
- Continuous spirometry

Invasive
- Flexible bronchoscopy

Prevention of displacement
Sedation and neuromuscular paralysis
Wiring the tube to upper teeth
Suspending the ventilator tubing close to DL-ETT

mechanically for the purpose of controlling and containing the spread of harmful fluid or secretions. In trauma, one indication is to prevent the spread of blood to normal lung parenchyma and allow for adequate alveolar capillary gas exchange.

There are several techniques available to achieve this goal, ranging from a simple mainstem bronchus intubation to the use of a DL-ETT or placement

Table 1
List of reported use of independent lung ventilation in trauma

Year	Author	Diagnosis and comment	N
1981	Miranda, et al [32]	Lung parenchymal hematoma—white lung 3 weeks after injury	1
1982	Dodds and Hillman [33]	Massive air leak	1
1984	Barzilay, et al [34]	Chest injury with flail chest	2
1985	Hurst, et al [35]	Severe unilateral pulmonary injury	8
1987	Crimi, et al [36]	Acute lung injury, three cases with bronchopleural fistula (BPF) and three cases without BPF	6
1989	Frame, et al [37]	Pulmonary contusion in a 6-year-old child	1
1989	Wendt, et al [38]	Unilateral chest trauma with BPF	1
1991	Jooss, et al [39]	Traumatic bronchial rupture	1
1991	Watts, et al [40]	Chest blast wound—shotgun	1
1992	Miller, et al [41]	Pulmonary contusion with massive hemoptysis	1
1997	Johannigman, et al [42]	Pulmonary contusion treated using independent lung ventilation (ILV) with nitric oxide	1
1997	Diaz-Reganon Valverde, et al [43]	26/45 acute respiratory distress syndrome (ARDS) caused by trauma, a controlled prospective study	26
1998	Ip-Yam, et al [44]	Unilateral ARDS caused by trauma in a 22 year-old patient treated with ILV-high frequency jet ventilation	1
1999	Pizov, et al [45]	Blast lung injury resulting from explosions on two civilian busses	15
1999	Wichert, et al [46]	Tracheal rupture near carina following blunt chest trauma	3
2001	Cinnella, et al [27]	Unilateral thoracic trauma—prospective study	12
2004	Moerer, et al [47]	Blunt chest trauma—total rupture of right mainstem bronchus	1
2005	Katsaragakis, et al [48]	Massive chest trauma with contusion, flail chest and pneumo–hemothorax and massive air leak	2

of a bronchial blocker with a single-lumen ETT (SL-ETT). All of these techniques can be performed blind but are preferably guided by a bronchoscope.

Two-lung–independent lung ventilation

TL-ILV is a mechanical ventilation strategy where independent ventilator circuits are used for each lung, working either synchronously or asynchronously. The purpose is to administer different modes of ventilation and/or different parameter settings to each lung.

In synchronous TL-ILV, the respiratory rate is kept the same between the two lungs but the cycle can be in phase or out of phase. Inspiratory flow rate, tidal volume (TV), and PEEP are set independently. This can be achieved by using either one ventilator system with a Y piece to accommodate separate PEEP valves, or two ventilators that are synchronized by using an external cable.

Asynchronous ILV must use two separate ventilators to be able to administer not only different ventilator settings but also administer different modes.

Anatomical separation

Anatomical separation is useful in chest trauma in cases of one-sided endobronchial bleeding with hemoptysis. OL-ILV can be achieved using an SL-ETT with endobronchial blocker or by use of selective DL-ETTs. OL-ILV provides limited respiratory support and is a short-term measure pending definitive management to control the bleeding site. Direct vision using flexible bronchoscopy will help to localize the bleeding site to guide the process of blockade and to suction the airways of blood and secretions. This will prevent the flooding of the remaining functioning alveoli with blood and thereby prevent further compromise of gas exchange. At present, however, there is no established consensus as to when to institute OL-ILV, whether before, during, or after damage control surgery. Regardless, the ultimate goal is to stabilize the airway status of the patient. Remember advanced cardiac life support… airway, breathing, circulation!

When site of bleeding is unknown, DL-ETT should be used instead of bronchial blockers. DL-ETT intubation may be difficult in the setting of massive bleeding, but it will permit bronchial toilet and limited bronchoscopic therapy [24]. After the bleeding is isolated and contained, any necessary definitive treatment should be sought expeditiously [49].

Physiological separation

Physiological separation is the process of ventilating each lung as an independent physiologic unit. In this case, the two lungs are managed using different ventilator modes and strategies (and potentially two different ventilators).

In complex thoracic injuries, there are situations in which there is an asymmetric or disproportionate degree of injury to the two lungs resulting in an asymmetric and disproportionate alteration in lung mechanics. Physiological separation with DL-ETT and TL-ILV can be implemented in asymmetric:

1. Pulmonary contusion
2. MAL or BPF
3. Bronchial injury

The clinical experience with the use of TL-ILV in bilateral lung injury is very limited.

Patient management under two-lung independent lung ventilation

Once the DL-ETT is in place and the patient has a secure airway, a plan for the ongoing management of the patient should follow. Initial vent settings should correspond to equivalent ARDSNet protocols, obviously adjusted for lung size; a 55%/45% ratio for right/left volumes should be used. These protocols are the result of data that showed that high levels of TV and/or airway pressure (P_{aw}) can harm the diseased lung parenchyma. Ventilation-induced lung injury (VILI) is a known complication of high TV and P_{aw} [52–54]. TL-ILV can selectively lower the TV and provide higher PEEP in the diseased lung to prevent further VILI. Maintaining the plateau pressure (P_{plat}) not greater than 30 cm H_2O to the diseased lung is suggested to prevent VILI [54]. Selectively titrating the TV and PEEP to the diseased lung by maintaining the P_{plat} less than 26 cm H_2O was shown to improve gas exchange and lung mechanics without affecting the hemodynamic status [27,48].

During ILV, monitoring of each circuit's airway pressures and compliance allows for adjustment of ventilator settings and avoidance of barotrauma to the less-diseased lung, as compared with conventional ventilation. PEEP is applied in amounts inversely proportional to lung compliance in an attempt to equalize the functional residual capacity of each lung. End tidal CO2 (Et-CO_2) is used as a measure of gas exchange, while P_{plat} and static compliance (C_{st}) are used as a measure of lung function. Equalization of TV use and Et-CO_2 level on both DL and NL was the criterion for switching from TL-ILV to SL-ETT conventional mechanical ventilation [27,55].

Pulmonary contusion

In most cases of minor pulmonary contusion, supplemental oxygenation by mask will be sufficient to prevent hypoxemia. Few adjuncts outside of endotracheal intubation are available to the trauma patient with pulmonary contusion. Although the use of biphasic positive airway pressure (BiPAP) has been described for managing hypoxemia in a patient with respiratory compromise, its usage is generally unwise in chest trauma patients. BiPAP predisposes to gastric distention and possible aspiration, especially in a population that may have depressed mental status at baseline because of injury or narcotic use. In these cases, prophylactic intubation should be instituted early on, before significant development of hypoxemia.

An extreme form of pulmonary contusion is seen secondary to blast injury, wherein the pulmonary contusion is diffuse and ill-defined. Several studies have used an extracorporeal shock wave lithotripter (ESWL) to induce a blast effect in a rat model. Results showed that the shock waves caused both intra-alveolar and intrabronchial hemorrhages, with an immediate threefold increase in lung weight [56,57].

These hemorrhages can complicate the mechanical ventilation of a non-compliant lung (either because of contusion or ARDS). Mechanical ventilation with higher mean airway pressure is therapeutic to counteract the low lung compliance seen in such cases. Strategies to achieve higher mean airway pressure include the use of positive end-expiratory pressure (PEEP), inspiratory/expiratory (I/E) ratio reversal, or use of a pressure control mode.

When the conventional methods of mechanical ventilation that have been described fail in a setting of an asymmetrical or a disproportionate degree of lung injury, intensivists may wind up resorting to more unconventional methods like ILV to maintain oxygenation.

In an asymmetric pulmonary contusion, lung compliance is lower in the affected side compared with the less or noninjured side. Patients with lung contusions thus may experience hypoxemia because of impaired gas exchange. A common tendency is to use higher PEEP and/or TV to recruit the diseased alveoli. This will lead to hyperinflation of the normal lung. In such cases, the use of SL-ETT with conventional mechanical ventilation will divert most of the TV to the more compliant lung, leading to barotrauma. Distention of normal alveoli causes a shift of blood flow to the nonventilated lung (nonrecruitable air spaces filled with blood or exudate, which will increase the intrapulmonary shunt fraction further.

The use of TL-ILV is beneficial in this subset of patients with asymmetric or one-sided lung contusion to allow different ventilator modes and settings. Initial volumes of 4 to 5 mL/kg per lung can be used, and this can then be adjusted according to target plateau pressures [27]. Furthermore, selective PEEP to improve recruitment in the diseased lung without overinflating the normal lung can be applied. Preferential PEEP can be adjusted to gas exchange parameters or mean airway pressures. A selective lung opening procedure [58] also can be applied, as an aide to the re-expansion of collapsed alveoli on the diseased side of the lung. ILV can be discontinued safely when the TVs and compliance of the lungs differ by less than 100 mL and 20% [27]. Other modes using TL-ILV selectively that have demonstrated success are synchronized pressure-controlled inverse-ratio ventilation (PC-IRV) [40] and high-frequency oscillatory ventilation (HFOV) [44].

Bronchopleural fistulas and massive air leaks

Large air-space leakages can occur in both blunt and penetrating chest trauma. Large volume losses tend to be related to a bronchopleural fistula (BPF). In blunt chest trauma, a massive air leak (MAL) can be from many disparate sources in an extensively damaged lung. In BPF, the air leak is typically through a single discrete pathway after a penetrating lung injury, following lung surgery, or following lung infection [59]. Ventilator management of BPF is often not applicable to management of MAL [60].

The treatment of BPF includes various surgical and medical procedures to reduce or seal the leak: manipulation of chest tube suction, HFOV [61], ILV, and bronchoscopic application of different glues, coils, and sealants [38,62–66]. Treatment options should be individualized depending on the site, size of BPF, and the severity of patient's comorbid conditions.

When conventional ventilation fails, ILV can administer mechanical ventilation selectively in the fistulous side by giving the lowest possible (TV), respiratory rate (RR), PEEP, and inspiratory time [24,60,67]. Conversely, HFOV is another technique that can be used to reduce the TV exchange [64]. Both strategies can minimize the air leak to hasten the healing of MAL and BPF.

Tracheo–bronchial injury

Tracheo–bronchial injury following blunt chest trauma is rare but potentially life-threatening. Trauma intensivists should have a high index of suspicion for this diagnosis, because there are no direct signs, and CT scan may fail to provide the diagnosis. Indirect signs of tracheo–bronchial injury include pneumothorax, pneumomediastinum, subcutaneous emphysema, or a nonexpanding lung after chest tube drainage of a pneumothorax. The fastest and most reliable diagnostic modality is the use of flexible bronchoscopy. After emergent surgical repair, TL-ILV is an option to protect the bronchial anastomosis during the early postoperative period [47].

Acute bilateral lung injury

Acute bilateral lung injury remains a controversial indication for the use of ILV. Before the era of ILV, HFOV using an SL-ETT was used in trauma-induced ARDS [8]. No specific modality of ventilatory support has been shown definitively to change the prognosis of ARDS. PEEP does not influence the course of the syndrome, nor does it prevent ARDS [68].

The idea behind using TL-ILV in bilateral lung injury is still the existence of asymmetry in the degree of contusion. Successful use has been reported in ARDS [43]. ILV can be combined with lateral decubitus positioning with the diseased lung on the dependent side. Application of selective PEEP to the more diseased lung/dependent side will recruit alveoli in the better-perfused, less-ventilated dependent side while diverting perfusion from the better ventilated nondependent side. Although some data show an improvement in gas exchange with use of ILV in bilateral lung injury, this remains a controversial strategy [43,69,70].

Less conventional strategies

There are times when the patient's disease process progresses beyond the capabilities of standard supportive care. This leaves the intensivist with other less well-described techniques to provide oxygenation. Some more extreme methods that have been described include: inhaled nitric oxide, prone positioning (PP), partial-lung liquid ventilation, and extracorporeal membrane oxygenation (ECMO).

Several published reports of these options showed promising results, while others were inconclusive. In the chest trauma literature, studies of this sort have been done mostly to treat trauma-induced ARDS. There are very limited data on the use of these techniques in the acute stage of pulmonary contusion-induced acute pulmonary failure (APF).

Nitric oxide

Nitric oxide, in combination with TL- ILV, was reported to be a complementary management strategy for unilateral pulmonary contusion [42]. Both therapies are intended to minimize volutrauma to the normal lung. Given as a gas, NO induces pulmonary vasodilatation in areas of normal alveoli, thus preferentially altering the ventilation–perfusion ratio. An acute lung contusion causes a ventilation–perfusion mismatch by obstructing gas exchange, similar to a primary intrapulmonary shunt. In a study by Johannigman and colleagues [42], the greatest improvement in pulmonary function was seen when NO was delivered to either the normal lung or to both lungs. This suggests that NO treatment using an SL-ETT with conventional mechanical ventilation may be a viable alternative to DL-ETT/TL-ILV for treating asymmetric lung contusion. Theoretically, the use of NO also may be beneficial for patients who have a bilateral lung injury consisting of multiple patchy contusions and acute respiratory failure.

Prone positioning

From a clinical point of view, PP is a promising treatment for ALI/ARDS, even though its use is not yet a standard clinical practice. The idea of using PP in trauma patients was patterned from Bryan and colleagues' [71] classic study using PP as a factor affecting regional distribution of ventilation and perfusion in the lung. In ALI/ARDS patients, PP leads to a reversal of the typical alveolar inflation and ventilation distribution, because of the reversal of hydrostatic pressure overlying lung parenchyma, the reversal of heart weight, and the changes in chest wall shape and mechanical properties.

Relatively little data are available addressing the modifications in regional lung perfusion. The possible mechanisms involved in oxygenation improvement during PP in ALI/ARDS patients are: increased lung volumes, redistribution of lung perfusion, and recruitment of dorsal spaces with more homogeneous ventilation and perfusion distribution [72]. In two small studies, Stocker and colleagues [73] and Fridrich and colleagues [74] investigated the effect of PP on trauma patients with sepsis and trauma-induced ARDS with good results. Repeated PP recruits collapsed lung tissue and improves gas exchange [75] with improved patient outcome [76]. Despite the general concern for safety, Michaels and colleagues [77] safely and effectively used PP in patients who had ARDS, including many with medical issues generally considered to be contraindications. PP was used in all patients, including those who had recent tracheostomies, open abdomen following damage control laparotomies, thoracotomies, extremity internal and external fixators, and central nervous system injuries, and during usage of large-bore continuous vascular access catheters (eg, ECMO or continuous venovenoushemofiltration), vasopressor therapy, and facial fractures.

Partial liquid ventilation

Partial liquid ventilation (PLV) first was reported in 1966 when Clark and Gollan [78] published its use in an animal study. Subsequent animal studies and a small number of human studies later reported overall improvement in lung compliance and gas exchange [79,80]. While receiving ECMO therapy in 10 adult patients with ARDS (1 trauma-induced), Hirschl and colleagues [81] reported that additional PLV treatment over ECMO showed better improvement in lung compliance and physiologic shunt.

These trials were performed using a perfluorocarbon solution to ventilate and oxygenate the lung. Perfluorocarbon is a highly dense insoluble liquid that allows free diffusion of O_2 and CO_2 in the alveolo–capillary interface when it is instilled into the airspaces of the lung. It also has surfactant properties and thus is capable of increasing alveolar surface tension. Because surfactant is deficient in ALI/ARDS patients, perfluorocarbon acts as liquid PEEP, recruiting collapsed alveoli and thereby improving oxygenation.

Anti-inflammatory properties also are attributed to perfluorocarbon. Smith and colleagues [82], in an in-vitro study, exposed alveolar macrophages to the solution, resulting in a decreased production of hydrogen peroxide and superoxide anions when compared with a control without perfluorocarbon. Other studies claim that perfluorocarbon has a local anti-inflammatory property in the alveolo–capillary interface, but the human ARDS study looking at its local anti-inflammatory effect was called into question as needing a better study protocol [83]. Despite all the theoretical beneficial properties of perfluorocarbon, trials in people who have respiratory failure have failed to show significant clinical improvement, especially in trauma patients.

Extracorporeal membrane oxygenation

The use of ECMO in trauma-induced APF first was reported by Hill and colleagues [84] in 1972. Subsequent to this, many controlled studies were performed that used ECMO for APF in mixed populations of trauma and nontrauma patients. Subsequent published reports have failed to demonstrate its benefit, with mortality rates between 50% and 90% [85–91].

When the lungs fail to act as a ventilation/oxygenation unit, and all known therapeutic options fail, ECMO can serve as a temporary lung replacement. ECMO functions to oxygenate the blood and remove carbon dioxide outside the body. In practical terms, it serves as an adjunctive treatment while allowing mechanical ventilation under minimal settings. Using very small amounts of volume, pressure, rate, and FIO2 prevents lung atelectasis, volutrauma, barotrauma, and oxygen toxicity. It is suggested that ECMO be used early on for a better response, at least within 5 days after starting mechanical ventilation [92,93].

ECMO can be compared with the process of hemodialysis. It uses a catheter (veno–venous or veno–arterial) connected to a machine. It is therefore not without complications. The use of heparin in the process may potentiate further bleeding in an already bleeding or coagulopathic chest trauma patient. ECMO is labor-intensive and requires a highly experienced critical care team.

In the same vein, ECMO, like hemodialysis, is a life support extender allowing intensivists to buy time for the lung to recuperate if at all possible. If the final outcome is end-stage lung disease, ECMO may serve as a bridge to lung transplant. At present, ECMO remains an invasive and expensive adjunct of unproven efficacy for the treatment of APF due to pulmonary contusion. At this point, because of its cost and complications, ECMO is reserved for those patients who have an isolated lung injury, with no other complicating factors preventing its use (eg, intracranial hemorrhage).

Summary

Patients who have severe chest trauma can present significant challenges to the intensivist. In most patients, the mainstay of care is primarily supportive. There is a subset of difficult multisystem-injured patients, however, that can tax an intensivist's ability to balance contradictory concerns such as the titration of a mean airway pressure in a patient who has a large volume air leak.

Tools such as those outlined in this article should be a part of the intensivist's armamentarium in dealing with these complex issues. The employment of these tools can be done most effectively with an understanding of the capabilities and drawbacks of all the techniques outlined here. The creative use of these tools demonstrates the potential elegance of the practice of the art of critical care, ultimately suiting the needs of the injured patient.

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