Extracorporeal life support in thoracic emergencies—a narrative review of current evidence

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Background and Objective: Resuscitative therapies for respiratory and cardiac failure are lifesaving and extended by using extracorporeal life support (ECLS) as mechanical circulatory support (MSC). This review informs the debate to identify the life-threatening thoracic emergencies in which patients may be cannulated for ECLS support.

Methods: An advanced search was performed in PubMed, Embase, Google Scholar, and references query, assessed in June 2022, identified 761 records. Among them, 74 publications in English were included in the current narrative review.

Key Content and Findings: ECLS is an additional tool for organ support in life-threatening thoracic emergencies. It provides bridging to recovery or to decision about destination as definitive therapy, intervention, or surgery. Non-traumatic emergencies include mediastinal mass, acute lung injury (ALI), aspiration, embolisms, acute and chronic heart failure. However, based on the current evidence, trauma, and especially blunt thoracic trauma, is one of the main indications for ECLS use in thoracic emergencies, among others in chest wall fractures, blunt and penetrating lung injuries. ECLS use is always individualized to patient's needs, injury pattern and kind of organ failure, circulatory arrest inclusive, depending on if respiratory or cardiac and circulatory support is needed. Further, ECLS offers the possibility for fast volume resuscitation and rewarming, thus preventing the lethal of trauma: hypothermia, hypoperfusion and acidosis. Anticoagulation may be omitted for some hours or days. Interdisciplinary cooperation between the intensivists, surgeons, anesthesiologists, emergency medical services, an appropriately organized and trained staff, equipment resources and logistical planning are essential for successful outcomes.

Conclusions: ECLS use in selected life-threatening thoracic emergencies is increasing. The summarized findings appeal to policymakers, and we hope that our summary of recommendations may impact clinical practice and research.

Keywords: Thoracic emergencies; extracorporeal life support (ECLS); extracorporeal membrane oxygenation (ECMO); hemorrhage; trauma

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Introduction

Background

The early pioneering cardiopulmonary bypass (CPB) technology (1), besides the application to perform planned cardiac surgery operations to treat acquired or congenital heart diseases, was used as temporary life support for patients with acute cardiac or respiratory failure. In 1972, a severe injured patient suffered several thoracic emergencies, among others including transection of thoracic aorta, as well multiple pelvic and lower limb fractures, after being struck by a motor vehicle (2,3). Four days later, he developed worsening acute respiratory distress syndrome (ARDS). On his sixth postoperative day, the first successful use of extracorporeal life support (ECLS), with a peripheral veno-arterial (V-A) configuration using a Bramson membrane heart-lung machine, was performed and continued for a total of 75 hours (3,4).

Rationale and knowledge gap

Over the last five decades, the use of ECLS has increased exponentially. ECLS provides temporary support of circulation and/or gas exchange bridging to recovery or to decision about destination as definitive therapy, intervention, or surgery. Historically, ECLS in trauma was considered as contraindication, due to coagulopathies and hemorrhage, difficulties in prone positioning, and need for further interventions and surgery (5,6). Due to advances in hemostatic resuscitation, percutaneous vascular cannula insertion, centrifugal pump technologies, and improvements in membrane oxygenators, there has been significant improvement in ECLS management and broadened indications for its use. However, its use in the trauma population remained controversial for a long time (6,7). An outcome analysis from Extracorporeal Life Support Organization (ELSO) registry showed that less than 1% of the adult ELSO registry population is diagnosed with a traumatic injury (6). In this cohort, thoracic injury was the most common diagnosis. The survival rates, comparable to other non-trauma groups, was reported by 70% at decannulation and 61% at hospital discharge (6). In parallel, the evidence for beneficial outcomes in hemorrhagic patients supported with ECLS is increasing (8). The benefits of hemodynamic support may outweigh the increased risk of bleeding since anticoagulation free protocols have been established thereby reducing or even preventing anticoagulation-related bleeding worsening due to ECLS application and support (8). Early stabilization with ECLS might prevent or overcome the vicious circle of the lethal triad of trauma: hypothermia, hypoperfusion and acidosis, causing coagulopathy (8-10).

ARDS is the most common, non-traumatic indication for respiratory support on ECLS. CESAR trial published in 2009, was the randomized study which compared ECLS with conventional treatment and highlighted the importance of involving specialized units, lung-protective ventilation, indicating ECLS as a valuable option in refractory respiratory failure (11). The results of EOLIA study brought further results suggesting a possible superior clinical advantage of ECLS used for respiratory support over conventional measures, particularly when extracorporeal membrane oxygenation (ECMO) is used early. Conventional therapies, including prone positioning, had a high failure rate, necessitating rescue ECLS. Even if the mortality at day 60 in ECLS 44/124 (35%) *vs.* control group 57/125 (46%) was not significant (12), based on the previous evidence ECLS is a well-established organ support and becoming a standard practice. The Bayesian analysis of EOLIA stated that ECLS did prove to be superior to conventional therapy and, therefore, is now a well-established and accepted organ support in lung failure and ARDS, as also shown in the coronavirus disease 2019 (COVID-19) period (13). The outcomes of veno-venous (V-V) ECLS in patients with severe COVID-related ARDS showed similar results as patients with non-COVID-related ARDS (14).

Respiratory and cardiac failure are commonly seen in the out-of-hospital scene, emergency department (ED), intensive care unit (ICU), and operating room (OR). Initial resuscitative therapies for these conditions are lifesaving and nowadays extended by using ECLS and mechanical circulatory support (MSC) techniques.

Objective

This review addresses the application of ECLS in the life-threatening thoracic emergencies. The new developed classification of trauma and non-trauma categories in thoracic emergencies in which patients may be cannulated for ECLS support is also presented. We present this article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-1307/rc).

Description and classification of thoracic emergencies

Respiratory and/or cardiac failure are common due to trauma or non-traumatic underlying diseases. They may also result in circulatory, distributive, or obstructive and hypovolemic shock. ECLS is an additional, advanced tool for lung and/or heart organ support and does not represent the treatment of the underlying disease. Mostly used application modes of ECLS are V-V and V-A. V-V ECLS is aimed for respiratory support in which cardiovascular function is not severely compromised. V-A ECLS targets supporting cardiac or combined cardiopulmonary failure. Another support option for combined cardiopulmonary failure is V-A-venous hybrid mode (V-AV), which included V-A and V-V support (15). Regarding the definition and classification of thoracic emergencies with potential use of ECLS, the list of the newly categorized patterns and indications are shown in *Table 1*.

Methods

An advanced search of PubMed, Embase, and Google Scholar through their databases using the following Medical Subject Headings (MeSH) terms: "extracorporeal membrane oxygenation" AND "wounds and injuries" OR "wounds, nonpenetrating" OR "wounds, penetrating" OR "crush injuries" OR "hypothermia" OR "burns" OR "mediastinal mass" and free terms: "extracorporeal life support" OR "ECLS" OR "ECMO" AND "thoracic emergency" OR "blunt trauma" OR "penetrating trauma" OR "combat" OR "critical airway" OR "REBOA" assessed in June 2022, identified 761 records. From those, 74 publications in English language were analyzed. Reference lists of assessed full texts were screened for further relevant studies (16).

We included prospective and retrospective cohort studies, cross-sectional studies, case-control studies, case series and case reports. Studies reporting on use of any type of ECLS in thoracic, lung and cardiac trauma, hemorrhage, combat and burn thoracic injuries, and airways emergencies were considered eligible (*Table 2*). Available evidence was summarized using narrative review methodology.

Mediastinal mass

Mediastinal masses are often initially asymptomatic. The late symptoms of the appear usually from either mass effects on adjoining structures, or paraneoplastic effects. Enlargement of mediastinal structures can cause severe respiratory impairment due to compression of the trachea and/or main bronchi. The stenosis of trachea and superior vena cava obstruction are secondary to compression from an enlarged mediastinal mass. Airway stents may provide effective and timely relief in patients with central airway obstruction. But severe, life- threatening respiratory failure may occur during such interventions. Thus, V-V ECLS is usually recommended in patients suffering severe hypoxemia and/or hypercapnia during invasive mechanical ventilation with exacerbating the risks of the mechanical ventilation induced lung injury (VILI). When committing an immunosuppressed patient to ECLS, patient selection and timing of initiation of these supports are the key considerations. ECLS use in immunocompromised patients with ARDS is increasing with 5% to 31% of patients receiving ECMO in recent studies. Because encouraging rates for hospital and long-term survival of immunocompromised patients in ICUs have been described, these patients are more likely to receive invasive therapies, also ECLS. Regarding the choice to perform ECLS or not, mainly due to possible complications of ECLS, as severe bleeding, the intensivists must take into account the future benefits of these patient.

Currently, ECLS may also be used as a protective bridging before, during and after interventions and procedures as among others, during induction chemotherapy and bronchoscopy intervention with stent placement preventing life-threatening deterioration. It leads to a paradigm shift in the pulmonary research.

Early V-V ECLS cannulation for respiratory support may improve survival in patients with mediastinal mass malignancies causing trachea obstruction and severe respiratory impairment. As configuration, femoro-femoral V-V cannulation is recommended as it enables stable blood flow avoiding the complications of superior vena cava obstruction.

ECLS in V-A configuration is used as a rescue management of anterior mediastinal masses with extrinsic compression on the airways and mediastinal vessels as well as during an emergent peri-arrest setting (17-20).

Tracheobronchial emergencies

The tracheobronchial tree plays a key role in ventilation. Any trauma, disruption or obstruction on these structures may be life-threatening and their treatment challenging, as in tracheal stenosis, tracheomalacia, tracheal tumors,

Table 1 Classification of thoracic emergencies (trauma and non-trauma, cardiac, parenchymal)

Organs or region	Trauma	Non-trauma
Respiratory		
Chest wall	Ribs, sternum, spine cord fractures	Chest wall tumor mass, compression, bleeding
Lung parenchyma	Contusion	ALI
	Post trauma ARDS	Atelectasis
	Penetrating injuries	Hemorrhagic condition (anticoagulants, coagulopathies due to hematological or rheumatological underlying disease)
	Bleeding	
Pleural	Pneumothorax	Tension- or spontaneous pneumothorax
	Tension- or hemopneumothorax	Hemopneumothorax (post-interventional complication)
Tracheobronchial system	Tracheal or bronchial rupture	Compression due to cervical mass (lymphoma, goiter)
	Difficult airway intubation	Trachea- or bronchial fistulas
	Aspiration (blood, stomach content)	Tracheal cannula dislocation
		Difficult airway intubation
		Aspiration (fluids, blood, stomach content, meconium in newborns)
Others	Burns, blast, and inhalation injury	Anterior mediastinal mass
	Drowning	
	Avalanche injury	
Cardiac		
Cardiac organ	Penetrating heart or great vessels injury	Chronic or acute heart failure due to underlying disease
	Aortic rupture or dissection	Cardiogenic shock
	Contusio cordis, luxatio cordis	Aortic dissection
Circulatory	Hemorrhagic shock (penetrating injury or bleeding coagulopathy)	Circulatory arrest
	Traumatic air embolism (due to long bone fracture)	Embolism (pulmonary artery embolism, amnion fluid embolism, air embolism)
Others		
Mediastinal	Esophageal rupture	Compression due to mediastinal tumor mass (lymphoma, retrosternal goiter)
	Trachea-esophageal fistula	Boerhaave syndrome (spontaneous esophageal rupture)
Hypothermia	Due to drowning or avalanche injury	Accidental
	Due to traumatic bleeding coagulopathy	Post-surgery
		Due to bleeding coagulopathy

ALI, acute lung injury; ARDS, acute respiratory distress syndrome.

iatrogenic tracheal injuries and foreign body aspiration. In these cases, emergency tracheostomy or coniotomy, cross field jet ventilation, direct cannulation of the distal trachea and small-bore endotracheal tubes can be employed (21). In several circumstances conventional ventilation is impossible. In such situation, ECLS may provide adequate oxygenation without the need for endotracheal intubation (22). This allows for an adequate respiratory support while performing surgery to restore the airway anatomy.

Iatrogenic tracheal injuries are a rare but life-threatening

Table 2 Summary of proceeding the database search for related publications

Items	Specification
Date of search	June 2022
Databases and other sources searched	PubMed, EMBASE, Google Scholar
Search terms used	MeSH: "extracorporeal membrane oxygenation", "wound and injuries", "wounds, nonpenetrating", "wounds, penetrating", "crush injuries", "hypothermia", "burns", "mediastinal mass"
	Free terms: "extracorporeal life support", "ECLS", "ECMO", "thoracic emergency", "blunt trauma", "penetrating trauma", "combat", "critical airway", "REBOA"
Timeframe of studies	1958–June 2022
Inclusion and exclusion criteria	Studies reporting on use of any type of ECLS in thoracic trauma, cardiac trauma, thoracic hemorrhage, combat and burn thoracic injuries, and airways emergencies were considered eligible
	Randomized clinical trials, controlled before-and-after studies, prospective and retrospective cohort studies, cross-sectional studies, case-control studies, case series and case reports. Conference abstracts, books, articles not written in English, and animal studies were excluded
Selection process	All the authors (AW, SM, JS, RL, JM) conducted the literature search and assessed the selected articles for inclusion. Consensus was reached when all the authors agreed on all studies

MeSH, Medical Subject Headings; ECLS, extracorporeal life support; ECMO, extracorporeal membrane oxygenation; REBOA, resuscitative endovascular balloon occlusion of the aorta.

complication of endotracheal intubation. Moreover, in 0.8% of blunt thoracic trauma victims, tracheobronchial injuries occur (23). Although a conservative approach is advised where possible, there are some cases which require surgical intervention (24). In distal airway ruptures, an endotracheal double lumen tube may prevent air leakage, tension pneumothorax or pneumomediastinum occluding the injured site. One-lung ventilation might be necessary but not sufficient for safe oxygenation (25,26). In such situations, a V-V ECLS can be used for respiratory support during surgery and post-operatively (24,27-31). V-V ECMO has been used during intraoperatively even for more complex procedures such as the repair of a tracheoesophageal fistula (32).

Further example of a critical airway condition foreign body aspiration. These patients can deteriorate fast due to asphyxia. Removing the foreign body with bronchoscopy is necessary but the bronchoscopy itself can cause intermittent complete airway occlusion due to manipulation in the main airways, aggravating the respiratory distress. V-V ECLS can support the respiratory system during the intervention, while extraction of the foreign body is performed (25).

Chest trauma and parenchymal injury

Thoracic trauma accounts for 20–25% of all trauma-related deaths (33-35). Thoracic injuries may include injuries to the airways, lungs, or parts of the cardiovascular system. The pathophysiologic mechanisms of a thoracic injury are multiple and include thoracic bone injuries, tracheobronchial injuries, pulmonary contusions or lacerations, pneumothorax and pleural effusion, acute airway obstruction, barotrauma, or restrictive intra-thoracic spaces (36). Overall, the survival of patients with thoracic trauma depends on the extent of injury and the techniques of support (37). Trauma itself and surgery in trauma patients require volume and blood products administration and can cause systemic inflammation and an increase of vascular permeability in alveolar capillaries. This results in fluid shifts, edema forming and alveolar damage, leading to decreased gas exchange and eventually to acute lung injury (ALI) and ARDS (35,38). Furthermore, ventilator-associated pneumonia (VAP) is a frequent complication. ARDS requires protective lung ventilation with low tidal volumes and safe positive end-expiratory pressure (PEEP) limits. In all these cases, ECLS could be an option to minimize the ventilatory settings when standard and advanced ventilation are failing and protective ventilation is required (35). ECLS initiation and cannulation strategy should be carefully chosen in thoracic trauma patients since several injuries may limit the insertion of a cannula through the traditional ways (36). Overall, V-V ECLS is the most used ECLS configuration for respiratory support while V-A ECLS is chosen in case of respiratory and circulatory support. In case of concomitant lung and right heart failure, a temporary right ventricular assist device with oxygenator (OxyRVAD) might be considered.

Results of ECLS use in chest trauma patients have been reported as positive by several small studies (39-41). Guirand *et al.* demonstrated that V-V ECMO was even associated with higher survival compared to conventional mechanical ventilation (41), mirroring the results of much larger studies performed in ARDS patients (42-45).

Prolonged mechanical ventilation (defined previously as longer than 7 days) was considered a relative contraindication for ECLS a decade or two decades ago, e.g., as an exclusion criterium for the CESAR trial (11). This exclusion criterium was chosen based on the rare use of lung protective ventilation in ICUs, and the frequent lung damage due to baro- and volu-trauma. On the other hand, the EOLIA trial, although known as "negative trial", showed that the conventional management (including prone positioning) had a high failure rate, necessitating "rescue" ECLS cannulation (12). Thus, based on the ELSO guidelines and available literature, prolonged ventilation is not considered as an ECLS contraindication anymore (46,47).

Transfusion-related ALI (TRALI), ARDS, and VAP may also lead to severe lung failure with life threatening complications, thus ECLS in chest trauma and parenchymal lung injury should be carefully considered. However, based on the current evidence, trauma, and especially blunt thoracic trauma is one of the main indications for ECLS in thoracic emergencies. Trauma patients are younger than non-trauma patients, and they have less comorbidities. In large cohort studies, the outcomes of trauma patients supported on ECLS are comparable to non-trauma patients, and not worse than them (6,48).

Thoracic penetrating injuries and hemorrhagic shock

Most penetrating injuries include direct damage to the intercostal or mammary arteries, pleura or lung tissue (34) and can be managed non-operatively with thorax drainage and conventional resuscitation techniques (35). However, in 10–15% of cases, an operative management is necessary. The main cause of morbidity and mortality in these patients is the hemorrhagic shock which is the second most frequent cause of death in trauma patients after nervous system injuries (49). Hemorrhagic shock and hemothorax can be a result of penetrating injury due to laceration of tine intercostal or mammary arteries, thoracic spine arteries, lung parenchyma, great vessels, thoracic aorta, and the heart (*Figure 1*).

Hemorrhagic shock after thoracic injury is managed by volume resuscitation and mass transfusion (8,34). Mass transfusion may lead to TRALI as well. The pathophysiology of TRALI is quite similar to ARDS (50). Multiple cases of V-V ECLS has been reported successful to support patients with TRALI where conventional treatment was not sufficient (51-54).

Historically, bleeding has been considered a contraindication (8,55,56). However, due to the systematic review performed by Willers *et al.* (8). ECLS for temporary circulatory support in refractory hemorrhagic shock is feasible based on tailored devices and adequate patient management. However, ECLS is not designed for bleeding control and it should not be considered as such "therapy". ECLS provides circulatory support that allows clinicians to gain time and bridge the patient to an appropriate medical, surgical, or interventional strategy for bleeding control, transfusions and coagulation supporting agents. Furthermore, new strategies and devices allows for a safer ECLS management in terms of anticoagulation (55).

ECLS might be indicated to support adequate tissue perfusion after the hemorrhagic shock, provide massive and quick transfusions, reduce systemic hypoxia and acidosis and prevent or treat hypothermia (8). Through these mechanisms, ECLS plays a pivotal role preventing or overcoming the vicious cycle of coagulopathy in hemorrhagic shock patients (57). Management of bleeding control, (surgical or interventional), transfusions and coagulation supporting agents is a separate strategy.

Aortic injuries

A direct penetrating injury or a complete transection of the aorta may cause exsanguination with pre-hospital death in 90% and 44% mortality of patients who make it to the emergency or OR (58). An aortic injury due to a blunt chest trauma is not always immediately lethal. Shearing forces due to rapid acceleration and deceleration on the aorta in blunt trauma may cause aortic dissection, typically at the ligamentum arteriosum where the aorta arch is fixed (59-61). Similarly, partial thickness injuries cause contained hematomas in the aortic walls. Patients with aortic injury need emergency surgery on CPB. However, these patients

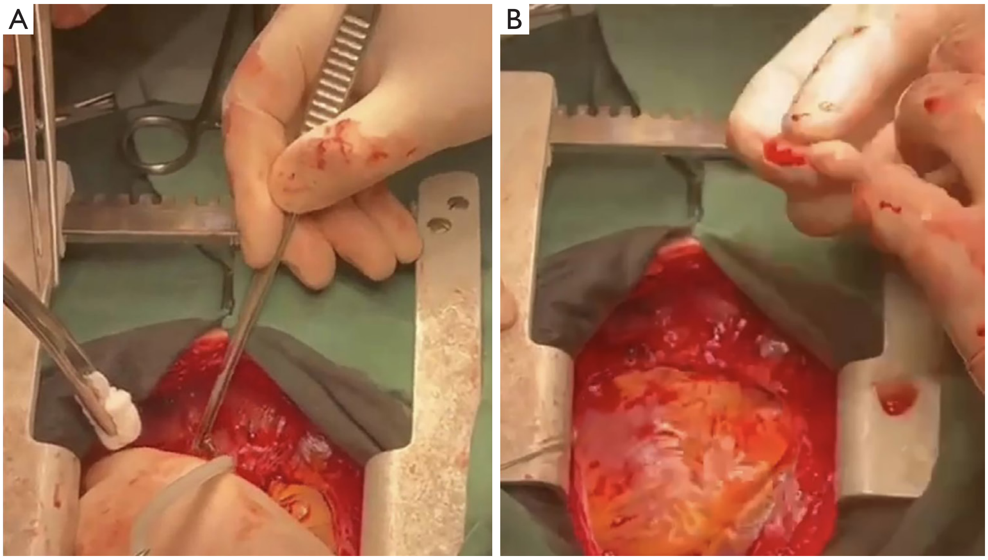

Figure 1 Projectile penetrating myocardium resulting in heart injury. (A) Splinter found in penetrating myocardial injury after combat injury in Ukraine. *In situ* corpus alienum pointed out by the forceps. (B) The corpus alienum is extracted from the patients, pointed out by the surgeon. With courtesy of Stepan Maruniak, MD, CCP, Department of Extracorporeal Methods of Treatment, Heart Institute Ministry of Health of Ukraine, Bratyslawska Str. 5A, 02166 Kyiv, Ukraine.

may rapidly deteriorate in the ED, aortic dissection may be misdiagnosed and/or cardiac surgery may not be available in every hospital. In such conditions, ECLS may be considered as a bridge to surgery and circulatory support but the evidence for ECLS in aortic injury is very scarce and controversial (15).

V-A ECLS is a potential option for refractory cardiogenic shock and cardiac arrest because it quickly improves hemodynamics and can be initiated rapidly. The most feared complication is the injury of the dissection membrane during the cannulation. In selected cases, the resuscitative endovascular balloon occlusion of the aorta (REBOA) might be required to control the massive hemorrhage from major vessels (62). Deployment of REBOA in the supra-diaphragmatic location (Zone I) allows for control of lower torso/abdominal or lower extremity bleeding. Zone II implies the placement of a REBOA between the celiac trunk and the renal arteries. Zone III involves REBOA placement below the renal arteries but proximal to the iliac bifurcation. ECLS can be applied also in combination with REBOA and a selective aortic arch perfusion (SAAP) to restore the circulation of the upper body in case of concomitant cardiac arrest or profound shock (63). In these cases, SAAP is a technique that combines thoracic aortic occlusion with a large-lumen balloon occlusion catheter inserted via a femoral artery and positioned between the left subclavian artery and diaphragm. The SAAP catheter lumen allows for extracorporeal perfusion with flow limited to the upper body to allow for adequate control of the hemorrhagic focus while maintaining the perfusion of the upper body. Although the concept of SAAP has been extensively evaluated in preclinical studies, its clinical use has not yet been described (63).

Emergency preservation and resuscitation (EPR) is a novel approach to the management of patients who have suffered a cardiac arrest from trauma such as in case of major thoracic hemorrhage or penetrating cardiac injury (63). This technique involves rapid cooling of the body and a period of circulatory arrest to allow for surgical hemostasis and a subsequent rewarming phase through ECLS. Profound hypothermia is induced by large-volume cold fluid infusion into the thoracic aorta and blood drainage from the right atrial appendage. Surgical hemostasis is then achieved under ECLS. This technique in currently under clinical investigation (64).

Blunt thoracic trauma

Based on the current evidence, trauma, and especially blunt thoracic trauma, is one of the main indications for

ECLS use in thoracic emergencies. Indeed, the use of ECLS in trauma is broadly increasing (6,15,57,65,66). Blunt thoracic trauma is often caused by high-energy trauma with compression, deceleration or inertial forces due to falls, motor vehicle collisions or by direct forces from assault. Blunt trauma forces on the thorax often cause rib fractures, resulting in higher mortality and risk for pneumonia, especially in elderly patients. An extensive trauma including four or more rib fractures increases the risk for ICU admission, intubation and ventilation (34). Furthermore, a high-energy impact on the thorax can cause pulmonary contusions, damage to lung parenchyma, alveolar lacerations and hemorrhage, followed by edema. This clinical picture can lead to ALI or ARDS (23,34), and to a ventilation-perfusion mismatch that will eventually result in shunting. In these cases, ECLS can be indicated to provide respiratory support as bridge to recovery (23). V-V ECLS is the first choice in case of good cardiac function, due to its lower bleeding risks. Overall, promising outcomes of V-V ECLS in trauma-related hypoxemia are reported, even when emergency surgery is performed (39,67-69).

Previous studies report a survival rate of almost 75–80% in thoracic blunt trauma supported by ECLS. V-V ECLS is the most often ECLS configuration used. Damage control surgery or invasive measurements were performed in 15–30% and hemorrhagic complications are reported between 29% of the cases, mostly at the surgical site and cannula site (39,70).

Cardiac trauma and traumatic cardiac arrest

Cardiac arrest caused by trauma is associated to a low survival rate, with a high incidence of permanent neurologic disability in survivors (71). The etiology of traumatic cardiac arrest can be categorized in three main groups: penetrating injuries, blunt injuries and hemorrhage-induced traumatic cardiac arrest (63,72).

Penetrating injury of the heart is nowadays rare in European countries. This kind of injury is one of the possible indications for ECLS, e.g., as bridging to surgery in case of hemorrhagic shock (*Figure 1A,1B*). Penetrating trauma is associated with better outcome than blunt mechanisms, but the location of the injury greatly affects survival (63). Indeed, some studies report a 94% pre-hospital mortality in patients with penetrating cardiac injury (23) and chances of survival to the hospital are reported between 6–19.3% (34). In most cases, survival depends on the rapidity of the patient transfer to a cardiac surgery center (73). Active bleeding and tamponade are the reason for severe hemodynamic instability in both penetrating and blunt injuries. Secondary myocardial contusion, myocardial stunning and/or infarction further complicate the clinical picture with acute heart failure. In these cases, the surgical control of the hemorrhage and the tamponade decompression are the treatment of choice. Simultaneously, V-A ECLS can provide adequate organs perfusion, rapid cooling of the body in case a circulatory arrest is required, therapeutic hypothermia and left ventricular unloading.

Blunt cardiac injuries include a wide range of clinical presentations, from ECG abnormalities to myocardial rupture and cardiogenic shock (23). In vehicle collisions, between 20–76% of death at scene is caused by blunt cardiac injuries (34) which usually include myocardial bruises, septal rupture with or without valvular injury, coronary artery injury and free wall ruptures. These injuries can result in direct congestive heart failure, myocardial infarctions and tamponade. Also arrhythmias can occur due to blunt chest trauma (34). When the cardiac function is not sufficient, an intra-aortic balloon pump can help to unload the left ventricle (23). However, unloading the left ventricle does not always secure sufficient cardiac function to maintain adequate tissue perfusion. In cases where cardiac function is significantly reduced, tissue perfusion must be supported with chronotropic and inotropic medications. ECLS can further support patients with deteriorated heart function whenever medical support is not sufficient (74). Indeed, patients with rupture of major vessels or cardiac rupture, cardiac arrest or valvular injury after blunt chest trauma have been successfully supported with ECLS (73,75-79).

Combat injuries

Recent years have witnessed a growing interest in the use of ECLS in military settings (80). Major traumas in battlefields are caused by explosions and are associated with inhalation, burn and blast injuries. There are four major types of blast injuries: direct tissue damage from pressurized waves, secondary injuries from penetrating wounds from projectiles, tertiary injuries from blunt or penetrating trauma caused by blast winds, and quaternary injuries including burns, radiation, and inhalation injuries (81). Soldiers exposed to explosions are thus at risk for multiple trauma injuries, including pulmonary injury. Blast lung injuries evolve to ARDS in 3–14% of patients sustaining primary blast injuries, associated with confined spaces

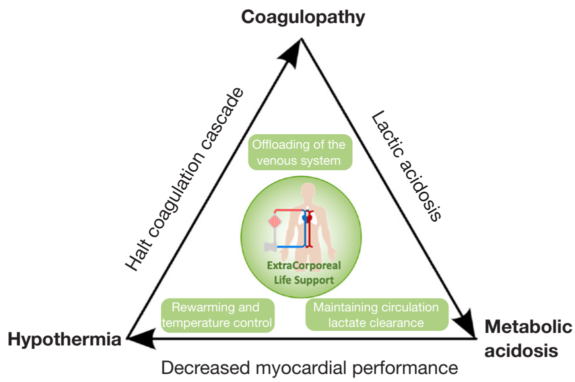

Figure 2 The triad of hypothermia, acidosis and coagulopathy causing further bleeding in hemorrhagic shock. ECLS used during the cardiopulmonary failure can restore the lethal triad characterized by metabolic acidosis, coagulopathy and hypothermia. ECLS, extracorporeal life support.

(82,83). Trauma patients in combat settings could benefit from fast respiratory and circulatory stabilization with ECLS so to allow a safer transport to a treatment facility. Literature reports few successful cases where interventional lung assists systems (iLA) were implanted to secure oxygenation during air transport as bridge to further treatments (84-86). Similarly, ECLS has been applied in ARDS after blast lung injury (87). Moreover, interfacility transport of patients submitted to ECLS has been improved and has proven to be safe an effective (88), supporting the growing role of ECLS as clinical approach for combat injuries (89). However, specialized teams are necessary to provide safe use of ECLS circuits and due to environmental factors, the use of ECLS on combat scenes is still very challenging.

Burn injuries

Burn and smoke inhalation injuries result in overwhelming inflammation activation with intra alveolar and intra bronchial damage with edema and hemorrhage. As a result, the lung compliance decreases, and alveolar gas exchange deteriorates. Finally, pulmonary shunting occurs, and hypoxemic respiratory failure can develop (90,91). Inhalation injury and sepsis leading to ARDS, multi-organ failure and shock have driven burn-related morbidity and mortality with 60% total body surface area involvement being a predictor of negative outcomes (92,93). Overall mortality of patients with burn inhalation injuries is reported between 16% and 85% in pediatric patients and 90% in the overall population (94,95). Successful use of ECLS in major burn injuries, with secondary ARDS, has been reported (90,96-103). Survival rates in these reports ranged between 28% and 87% (90,100,104). Nevertheless, limited evidence is reported. No large cohorts have been described and evidence of successful use of ECLS is only based on case series or case reports which might be biased and overestimate the survival rate of this specific patient group.

Benefits of ECLS in trauma patients

Trauma patients are conventionally treated with fluid resuscitation, ventilatory support and chest tube drainage. In cases of traumatic cardiorespiratory arrest, survival decreases to 17% (105). ECLS used during the cardiopulmonary failure can restore the lethal triad characterized by metabolic acidosis, coagulopathy and hypothermia (106) (*Figure 2*). ECLS may quickly restore the circulatory volume allowing for a resuscitation of 4L within 30 minutes with the use of normal to large size cannulas. With resuscitation and continuous cardiac support, circulation is restored and can therefore correct the metabolic acidosis. Furthermore, accidental hypothermia can be corrected with central rewarming via ECLS. Whenever there is cerebral injury, ECLS can be used in blood cooling to protect the cerebral tissue. By reversing hypothermia, coagulopathy can be reversed as well (57).

Limitations of ECLS in trauma patients

There are still concerns to the use of ECLS in trauma patients. First, by reversing hypothermia, coagulopathy can be prevented. But the use of ECLS, with foreign body cannulas and surfaces and the use of systemic anticoagulation, may promote the development of coagulopathy. In addition, the specific concern in trauma patients is further exsanguination during ECLS. In the past few years, the knowledge and experience with the use of ECLS has been expanding rapidly. ECLS systems have been improved with heparin bonding and modifications in the systemic anticoagulation management have been developed, decreasing the incidence of bleeding complications (35,57). A systematic review of patient with pre-existent hemorrhage, showed good outcomes of ECLS support with a survival rate of 82.3%. Only 26% of patients developed bleeding complications. Multiple solutions to minimize the risk of further bleeding, include an initial heparin-free period, lower heparin targets or clamping of the tube in pulmonary bleeding (8). However, anticoagulation strategies and timing of ECLS initiation in trauma patients are still controversial (107).

Further research is needed to improve the use of ECLS in trauma. However, a low number of trauma patients submitted to ECLS complicates this. Most papers are case series of small cohorts. Research on prediction of survival is therefore difficult. Adding a trauma addendum to the previously mentioned ELSO registry, could contribute to further research.

Conclusions

ECLS use in thoracic emergencies is increasing. The summarized findings appeal to policymakers, and we hope that our summary of recommendations may impact clinical practice and research. ECLS use is always individualized to patient's needs, injury pattern and kind of organ failure, circulatory arrest inclusive, depending on if respiratory or cardiac and circulatory support is needed. It is recommended to adjust anticoagulation targets to patients' condition. Anticoagulation may be omitted for some hours or days. Daily, routine oxygenator checks are obligatory. ECLS is an additional tool for organ support and cannot be understand as a treatment of the underlying disease. ECLS provides bridging to recovery or to decision about destination as definitive therapy, intervention, or surgery. Interdisciplinary cooperation between the intensivists, surgeons, anesthesiologists, emergency medical services, an appropriately organized and trained staff, equipment resources and logistical planning are essential for successful outcomes.

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