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ORIGINAL ARTICLE

Emergency department thoracotomy in a physician-staffed trauma system: the experience of a French Military level-1 trauma center

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Abstract

Purpose To investigate survival after emergency department thoracotomy (EDT) in a physician-staffed emergency medicine system.

Methods This single-center retrospective study included all in extremis trauma patients who underwent EDT between 2013 and 2021 in a military level 1 trauma center. CPR time exceeding 15 minutes for penetrating trauma of 10 minutes for blunt trauma, and identified head injury were the exclusion criteria.

Results Thirty patients (73% male, 22/30) with a median age of 42 y/o [27–64], who presented mostly with polytrauma (60%, 18/30), blunt trauma (60%, 18/30), and severe chest trauma with a median AIS of 4 3–5 underwent EDT. Mean prehospital time was 58 min (4–73). On admission, the mean ISS was 41 29–50, and 53% (16/30) of patients had lost all signs of life (SOL) before EDT. On initial work-up, Hb was 9.6 g/dL [7.0–11.1], INR was 2.5 [1.7–3.2], pH was 7.0 [6.8–7.1], and lactate level was 11.1 [7.0–13.1] mmol/L. Survival rates at 24 h and 90 days after penetrating versus blunt trauma were 58 and 41% versus 16 and 6%, respectively. If SOL were present initially, these values were 100 and 80% versus 22 and 11%.

Conclusion Among in extremis patients supported in a physician-staffed emergency medicine system, implementation of a trauma protocol with EDT resulted in overall survival rates of 33% at 24 h and 20% at 90 days. Best survival was observed for penetrating trauma or in the presence of SOL on admission.

Keywords Traumatic cardiac arrest · Thoracotomy · Aortic occlusion

Abbreviations

ABG	Arterial blood gas
ACDS	Advanced course for deployment surgery
AIS	Abbreviated injury scale
BP	Blood pressure
CPR	Cardiopulmonary resuscitation
ER	Emergency room
EDT	Emergency department thoracotomy
FAST	Focused assessment with sonography in trauma
FFP	Fresh-frozen plasma
FLYP	French lyophilized plasma
GOS	Glasgow outcome scale
GOSE	Extended Glasgow outcome scale
HR	Heart rate
ICU	Intensive-care unit
IQR	Interquartile range
LOMI	Location of major injury
MOI	Mechanism of injury
NTDB	National trauma databank
RBC	Packed red blood cell
REBOA	Resuscitative endovascular balloon occlusion of the aorta
SBP	Systolic blood pressure
SOL	Signs of life

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Introduction

Emergency department thoracotomy (EDT) is a potentially life-saving procedure for trauma patients arriving in extremis at hospital; it seems to be particularly promising

in the French physician-staffed emergency medicine system [1–3]. This standardised surgical manoeuvre aims to solve reversible causes of traumatic cardiac arrest by removing a compressive pleural or pericardial effusion, carrying out temporary intra-thoracic haemostasis, and continuing internal cardiac massage with emphasis on coronary and cerebral perfusion by clamping the descending thoracic aorta [1].

EDT is usually performed on patients suffering either recent post-traumatic cardiac arrest or refractory shock, defined by a persistent SBP < 60 mmHg after 5 min of intensive resuscitation. Survival rate after EDT ranges from 5 to 12% after blunt trauma and from 20 to 42% after penetrating trauma in European trauma settings [4, 5]. As this outcome is at variance with the previous reports, EDT remains a procedure implemented on a case-by-case basis with controversial evidence regarding the ideal indications. Moreover, international guidelines for the management of post-traumatic cardiac arrest are mainly based on the US civilian and military literature. Facing a high incidence of penetrating trauma, the US trauma system is based on a staggered territorial organisation, paramedic prehospital care, as well as specialised surgical training in traumatology [7].

The considerable heterogeneity in prehospital care and ER trauma protocols in the previous reports has limited the extrapolation of their results to the French trauma system based on physician-staffed prehospital care. This procedure, which was the subject of national guidelines on the management of severe chest trauma patients in 2015, remains marginal in France [6]. This open-chest resuscitation technique is not widely reported in the literature, particularly when it is performed on admission in the emergency room (ER) as part of a standardised trauma protocol [3]. The objective of this study was to describe EDT practices in a French level-1 trauma center, detailing survival rates at 24 h and 90 days and its main contributing factors: mechanism of injury (MOI), presence of signs of life (SOL), location of the major injury (LOMI), prehospital time, transfusion protocol, and neurological outcomes.

Materials and methods

Study design

We conducted a monocentric retrospective observational study using data from our prospective registry of severe trauma patients. This registry was created in 2013 and included all patients with suspected major trauma admitted to our institution. As a regional level-1 trauma center, the Sainte Anne Military Teaching Hospital in Toulon is part of the civilian trauma system for the Provence Alpes Côte d'Azur region, set up in 2013. Approval was obtained from the ethics committee of French Society for Thoracic and Cardiovascular Surgery (FSTCVS) under registration number 2019-18.

Population

From January 2013 to August 2021, all major trauma patients over 15 years old arriving in extremis in the ER, suffering from either penetrating or blunt trauma, presenting with signs of life (SOL) during initial care and recent cardiac arrest or refractory shock on admission were included.

Patients suffering from cardiac arrest whose CPR time exceeded 15 min after penetrating trauma or 10 min after blunt trauma were not eligible for EDT and so were excluded. Patients presenting with a head injury identified by anisocoria were excluded. Patients in refractory shock who initially underwent resuscitative endovascular balloon occlusion of the aorta (REBOA) were not included.

Interventions

EDT was implemented within a trauma protocol on admission to the ER and was decided jointly by the intensivist, trauma leader, and the surgeon on duty, designated as the surgeon-in-charge. This could be either a visceral or a thoracic and vascular board-certified surgeon, holding the French Advanced Course for Deployment Surgery (ACDS) [8]. A thoracotomy set was available in each of the two ERs. Beginning with a left anterior thoracotomy, the salvage thoracotomy was enlarged in mirror image at the slightest doubt of contralateral effusion or difficulty in exposing the mediastinum. The procedure aims to open the pericardium, and to perform either supra-diaphragmatic aortic cross-clamping or internal cardiac massage[1–9]. A transfusion strategy was initiated on admission as part of a massive transfusion protocol with a minimum of two units of packed red blood cell (RBC) and two units of fresh frozen plasma (FFP) or French lyophilized plasma (FLYP); this strategy has been used since 2015. Transfusion was continued in cases of haemorrhagic shock following a 1:1 plasma:RBC ratio, regarding vital signs, blood samples, and ROT®. The trauma protocol also provided for the IV infusion of 2 g of Ca^{2+} and fibrinogen as soon as the injured person was admitted. The decision to stop treatment was made in a collegial manner after 30 min of invasive CPR without recovery of a spontaneous heart rhythm.

Outcomes

To describe EDT practice in a French level-1 trauma center, the primary endpoint was the overall survival rate at 24 h and 90 days, defined by MOI and presence of SOL. Secondary, we aimed to describe prehospital management, ER

trauma protocol implementation, OR findings, and 90-day follow-up.

- Prehospital management was described by the collection of the first clinical and biological parameters: MOI, vital signs (HR, SBP, SpO_2), live-saving procedures (pleural decompression, intubation, CPR), and transfusion. Prehospital time was noted.
- The data collected on ER admission were clinical (SOL, vital signs, FAST) and biological (ABG, blood count and coagulation test). The transfusion strategy (RBCs, FLYPs, FFPs) and surgical resuscitation procedure were detailed. ER staying time was reported. The operating room (OR) findings such as LOMI and damage control (DC) gestures were noticed.
- All survivors transitioned from the ICU to general care unit before their admission in a rehabilitation center. The Glasgow Outcome Scale (GOS) at ICU discharge was noted. The 90-day visit was carried out by the referring surgeon without any neurological complications being hinted at in the reports. At the time of the study, the referring surgeon performed the Standardised Post Discharge Structure interview for the Extended Glasgow Outcome Scale Extended (GOSE). Mortality at 24 hours and 90 days, and the location of death (ER, OR, ICU) were detailed.

Statistical analyses

Statistical analyses were carried out using SPSS 25 software (IBM). Descriptive statistics were performed on patient characteristics. Continuous variables are expressed as medians and interquartile range (IQR). Categorical variables are presented as ratios and percentages. Data from penetrating trauma were compared with blunt trauma over the same period. Similarly, data from survivors were compared with data from non-survivors. Bivariate analysis of categorical variables was performed using the chi-squared test. Continuous variables were compared using the Mann–Whitney test.

Results

Population

During the study period, 30 patients underwent EDT upon ER admission. The characteristics of the population are summarised in Table 1. The majority were male ($n = 22/30$; 73%) and in the fifth decade of life decade (median 42 y/o; IQR [27–64]). Twenty-four of the cases involved thoracic trauma. More than one in three patients ($n = 12/30$; 40%) suffered from penetrating trauma, mainly gunshot wounds (8/12). On admission, the ER team faced patients in extremis, as suggested by an estimated ISS > 25 [41; 29–50] and a reported shock index (HR/SBP) > 1 (2.0; [1.8–2.5]). Immediate blood sampling on admission showed anaemia, with a loss of 4 haemoglobin points compared to the norm, consumption coagulopathy, and severe lactic acidosis, i.e., components of the lethal triad.

Management

The main outcomes are presented in Table 2. The median prehospital time was 58 [45–73] min without any difference between survivors and non-survivors at 24 h (54.5 [42.5–61.3 vs. 60 [45–76]], $p = 0.374$). During this time, one in two patients (15/30) experienced on-scene CPR, one in three received a pleural decompression, and one in eight received a prehospital transfusion (4/30). On-site orotracheal intubation with mechanical ventilation during transport was performed in 24 patients.

On admission, 6 patients out of 15 who suffered out-of-hospital cardiac arrest had recovered a heart rhythm during prehospital care and underwent EDT for refractory shock. For 16/30 patients suffering cardiac arrest in the ER, 10/16 EDT were performed through a clamshell thoracotomy. Aortic occlusion was achieved through a left anterolateral thoracotomy for most patients suffering either refractory shock (12/14) or extra-thoracic trauma (6/30). The procedure leading to aortic occlusion was completed for most patients (26/30). A FAST was systematically performed before the procedure and revealed a pleural, pericardial, or peritoneal effusion in 20/26 cases (four had missing data). The median time in the ER was 38 [30–80] min, 36.5 min [19–64] for survivors at 24 h, vs. 42 min [30–88] for non-survivors at 24 h, $p = 0.324$. At 6 h after admission, the median transfusion was 7[4–10], RBCs and 6 [4–10] FLYPs or FFPs per patient without any difference between survivors vs. non-survivors at 24 h: 8 [5–13] vs. 8 [5–11], $p = 0.399$, and 7 [4–13] vs. 7 [4–11], $p = 0.334$, respectively. The mean ratio of blood products transfused per patient at 24 h was 12.8 [5.25–17.5] RBCs, and 10.8 [4–14] FLYPs or FFPs.

Three patients (3/30) died in the ER after 30 min of invasive CPR, 22/30 were directly taken by stretcher to the OR, and 5/30 with a negative FAST result were transferred for a CT scan. Studying survivors at 24 h vs. non-survivors at 24 h, patients died in ER in 0/20 vs. 3/10 cases, $p = 0.101$, reached the OR in 9/10 vs. 13/20 cases, $p = 0.317$, or were transferred to CT scan in 1/10 vs. 4/20 cases, $p = 0.317$. Spinal injury above T6 potentially as a source of neurogenic shock was revealed in four patients as the LOMI. OR findings and DC gestures are reported in Table 3. After 2016, aortic occlusion by EDT has been secondarily switched in the OR to zone 3 REBOA in cases of persistent cardiac activity without confirmed abdominal or thoracic bleeding, as a bridge

Table 1 Characteristics of the population.

	All patients included $n=30$	Non-survivor at 24 h $n=20$	Survivor at 24 h $n=10$	p
Demographics				
Age, years	42 [27–64]	44 [28–66]	41 [22–61]	0.443
Gender: male	22 (73)	13 (65)	9 (90)	0.210
MOI				0.045
Blunt	18 (60)	15 (75)	3 (30)	
Penetrating	12 (40)	5 (28)	7 (70)	
Number of lesions > 2	18 (70%)	9 (45%)	3 (30%)	0.694
ISS	41 [29–50]	41 [34–50]	34 [23–48]	0.092
AIS thorax	4 [3–5]	4 [3–5]	4 [0–4]	0.223
AIS abdomen	3 [0–4]	2.5 [0–4]	4 [3.5–5]	0.011
AIS lower extremity	2 [0–4]	4 [0–4]	0.5 [0–2]	0.060
Prehospital time				
Maximal heart rate, bpm	128 [110–138]	128 [111–138]	122 [105–142]	0.925
Minimal SBP, mmHg	80 [61–90]	80 [60–90]	80 [58–91]	0.976
Cardiac arrest	15 (50)	12 (60)	3 (30)	0.245
Pleural decompression	9 (32)	8 (40)	2 (20)	0.417
Transfusion	4 (14)	1 (5.6)	3 (30)	0.116
ER time				
Maximal heart rate, bpm	117 [107–135]	119 [104–133]	117 [105–139]	0.962
Minimal SBP, mmHg	60 [50–60]	60 [54–60]	57 [49–65]	0.468
Shock Index	2 [1.8–2.5]	1.9 [1.7–2.5]	1.9 [1.8–2.7]	0.455
Haemoglobin, g/L	9.6 [7–11.1]	8.3 [6.5–10.5]	10.6 [10.1–12]	0.008
Platelets, G/L	122 [86–160]	117 [85–137.5]	145 [78–198]	0.713
INR	2.5 [1.7–3.2]	2.7 [1.9–4]	2.8 [1.6–3]	0.212
Fibrinogen, g/L	1 [0.7–2.2]	1.1 [0.6–2.9]	1.5 [0.8–2.2]	0.461
Lactate, mmol/L	13.1 [7–11.1]	16 [11.1–19.5]	8 [6.5–13.5]	0.059
pH	7 [6.8–7.1]	6.8 [6.8–7.1]	7 [6.9–7.2]	0.143
Base excess	− 17.5 [− 24.3–− 11]	− 20 [− 24.8–− 13.8]	− 11 [− 19–− 10]	0.111
Indication for EDT				0.442
Cardiac arrest	16 (53)	12 (60)	4 (40)	
Refractory shock	14 (47)	8 (40)	6 (60)	
Surgical approach for EDT				0.999
Left lateral thoracotomy	12 (40)	8 (40)	4 (33)	
Clamshell	18 (60)	12 (60)	6 (60)	

Data are presented either as counts (n, % of total), or medians [IQR]

MOI mechanism of injury, *ISS* injury severity score, *AIS* abbreviated injury scale, *SBP* systolic blood pressure, *ER* emergency room, *EDT* emergency department thoracotomy

to arterio-embolization for pelvic injuries (3/30). Concerning patients with a thoracic LOMI, 2/10 supporting cardiac luxation survived at 24 h, and 1/10 with a stab cardiac wound is still alive. Eight patients with extra-thoracic bleeding, mainly in refractory shock (5/8), survived after EDT. Among the long-term survivors, 4/6 presented with a gunshot wound. Iatrogenic heart laceration on clamshell thoracotomy was reported for one case of abdominal trauma.

Follow-up

At ICU discharge, the GOS rated the patients' status into five categories: 1/Dead (15/21), 2/Vegetative state (0/21), 3/Severe disability (1/21), 4/Moderate disability (2/21), and 5/Good recovery (3/21). Using the standardised post-discharge interview for GOSE, more than 2 years after the EDT, survivors' status was categorised as upper moderate

Table 2 Outcomes of all patients included according to the MOI (blunt or penetrating trauma)

	Blunt trauma $n=18$	Penetrating trauma $n=12$
Survival		
24 h	3 (17)	7 (58)
90 days	1 (6)	5 (42)
Location of death		
ER	1 (6)	3 (25)
OR	3 (17)	2 (17)
ICU	13 (72)	2 (17)
GOS at ICU discharge		
1. Dead	17(94)	7 (58)
2. Vegetative state	0	0
3. Severe disability	1 (6)	0
4. Moderate disability	0	2 (17)
5. Good recovery	0	3 (25)

Data presented are presented either as counts (*n* and % of total)

MOI mechanism of injury, *ER* emergency room, *OR* operating room, *ICU* Intensive-care unit, *GOS* Glasgow outcome scale

disability (MD+) (2/6), lower good recovery (GR−) (1/6), and upper good recovery (GR+) (3/6).

Overall, the survival rate was 33% at 24 h and 20% at 90 days (Fig. 1). The survival rates at 24 h and 90 days were significantly higher in the penetrating trauma group, with 58% (7/12) vs. 17% (3/18) ($p=0.020$) and 42% (5/12) vs. 6% (1/18) ($p=0.017$), respectively. All penetrating trauma patients with refractory shock when EDT was performed survived at 24 h and 80% were still alive at 90 days. The median length of stay in the ICU was 19 days and the median length of hospitalisation was 28 days for these long survivors. There was no significant difference in prehospital management between survivors and non-survivors. Survivors had significantly more penetrating trauma (70% versus 25%; $p=0.045$) and more severe abdominal injuries: AIS abdomen was 4.0 [3.5–5.0] versus 2.5 [0.0–4.0]; $p=0.011$. The survivors seemed to be less severely injured than the non-survivors at admission (ISS = 34 [23–48] vs.41 [34–50]; $p=0.092$). Blood loss in these patients also appeared to be less severe (Hb: 10.6 g/dl [10.1–12.] vs.8.3 [6.5–10.5] g/dl; $p=0.008$).

Table 3 Damage control surgery according to the location of major injury (LOMI).

LOMI	ER gestures	(n)	OR additional procedures	(*n*)
Thorax ($n=10$, 33%)				
	Aortic occlusion	8	Pleural packing	2
	Cardiorrhaphy	2	Pneumorraphy	2
	Pulmonary hilum clamping	1	Abbreviated laparotomy	3
	Cardiac luxation reduction	3	Perihepatic packing	1
			Splenectomy	1
			Gi stapling	1
Abdomen ($n=9$, 30%)				
	Aortic occlusion	8	Pleural packing	1
			Cardiorrhaphy	1
			Abbreviated laparotomy	6
			Splenectomy	2
			Gi stapling	5
			Vascular shunt	2
			Perihepatic packing	3
			Preperitoneal packing	1
Pelvis and groin ($n=6$, 20%)				
	Aortic occlusion	6	Abbreviated laparotomy	
			Preperitoneal packing	
			REBOA	
Head and spine ($n=5$, 16%)				
	Aortic occlusion	4		

Data presented are presented either as counts (*n*, % of total)

LOMI location of major injury, *ER* Emergency room, *OR* operating room, *GI* gastrointestinal, *REBOA* Resuscitative endovascular balloon occlusion of the aorta

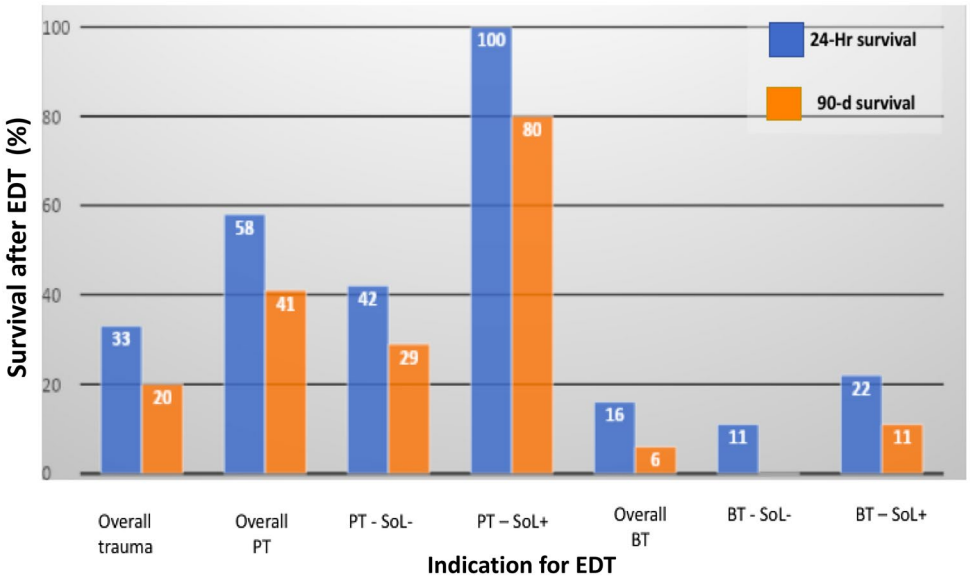

Fig. 1 Survival at 24 h and 90 days of all patients included according to the MOI (blunt or penetrating trauma) and the presence of SOL

Discussion

The implementation of EDT resulted here in an overall survival rate of 33% at 24 h and 20% at 90 days for patients in extremis, supported by a physician-staffed trauma system. These values were almost doubled for penetrating trauma and tripled if SOL were present. Considering MOI, our results are consistent with a recent systematic review of the European experience of EDT (Croatia, Norway, Denmark, Iceland, The Netherlands, Scotland, and Switzerland): 12.9% patients survived after blunt trauma (18/139) and 41.6% after penetrating trauma (37/89) when thoracotomy is performed in the ER [5]. Reflecting a US-inspired trauma system, a German trauma registry analysis reported a lower survival rate after EDT of 4.8% for blunt trauma and 20.7% for penetrating trauma, doubling the survival rate reported in US national cohorts [4, 10–12].

The observance of the US guidelines of the Western Trauma Association in our institution led to the proposal of EDT in the case of refractory shock regardless of the MOI and contributed to the overall survival rate described here in moribund patients, as was already noted by an Italian trauma team [7, 12, 13]. Neither the population nor the intervention could explain the higher survival in our series compared to US series. To compare, all of the patients from our series had an ISS > 29, which corresponds to the 5% highest severe trauma patients of the US National Trauma Data Bank [14, 15]. As it seems to be increasingly recommended, the approach used here was mainly a clamshell thoracotomy as it is taught in French war surgery courses [1, 9, 16, 17]. Following an institutional research program, endovascular aortic occlusion by REBOA has been preferred for patients in refractory shock with extra-thoracic trauma to aortic occlusion through a left anterolateral thoracotomy since 2016. Although the design of this retrospective study did not allow us to compare REBOA vs. EDT in this indication, a high level of evidence supports REBOA as the first-line therapy in this case [18]. Moreover, as we described here, REBOA and EDT appeared to be complementary: three times, EDT was switched to zone 3 REBOA in the OR when there was neither thoracic nor abdominal bleeding, to prevent prolonged digestive and renal ischemia in case of pelvic or limb injury.

To date, this is the second French cohort describing a population of patients who have benefited from EDT in a physician-staffed emergency medicine system. The demographics of this series are comparable to the experience of 22 patients in Grenoble reported by Mancini et al. in 2017 [3]. The better survival described here could be related to a higher recourse to EDT, with four EDT/year. This could be explained by the implementation of EDT within trauma protocols, decision-making by a surgeon/intensivist duo, and trauma-trained ER teams for military prospects [19]. Thus, it is evidence that the training of multidisciplinary teams in technical and non-technical skills benefits trauma patients with higher severity and, specifically concerning EDT, an increase in the survival rate has already been noted in relation with the diffusion of this practice [12, 20]. Here, the mean ER staying time, that aimed to be less than 40 min, was only 38 min, which demonstrated the key concept to improve chance of survival for these critical patients was to transport them to OR or ICU as soon as possible for definite care without any delay [18]. It suggested both effective trauma teamwork and prompt decision-making to make EDT being the way to buy time but not wasting time.

An important comment concerns survival after blunt trauma. The Eastern Association for the Surgery of Trauma has already issued recommendations not to perform EDT

on patients without SOL in blunt trauma, as it seems futile because of the low survival rate reported [21, 22]. In our series, nine EDT were carried out under these conditions, in the seconds following cardiac arrest, and none of the patients survived. This highlights the difficulty of EDT decision-making: to limit therapeutics in young patients in an emergency situation on the one hand and to desire to exclude all reversible causes of traumatic cardiac arrest on the other. A survey of 540 trauma surgeons regarding EDT decision-making revealed that 47% of them had performed an EDT for blunt trauma when SOL disappeared [23].

Finally, it should be emphasised that EDT was associated with a significant increase in survival rate despite prolonged prehospital time, known as an independent predictor of mortality in a physician-staffed emergency medicine system, where the odds of death increased by 9% for each 10-min increase in prehospital time [24, 25]. Moreover, the location of admission of patients arriving in extremis in the ER could be criticised. Included in the last European systematic review, the Swiss experience has underlined that the survival of these patients was superior when EDT was performed in the OR rather than in the ER [5, 26]. However, patients undergoing this open-chest resuscitation manoeuvre in the ER versus in the OR presented with more stage 3 or 4 haemorrhagic shock and a lower SBP in this study. The timing of EDT seems to be more important than its location. The ideal would be to receive major trauma patients in a hybrid room, thus allowing a unity of location from diagnosis to treatment of truncal haemorrhages, as has been reported by Japanese trauma teams [27, 28].

Limitations

This study has numerous limitations, linked to its retrospective, monocentric design and the small number of patients. In this respect, it would be appropriate to carry out a national multicentre study to shed light on this practice in France and its interest in a physician-staffed emergency medicine system.

Conclusion

The implementation of EDT in the ER trauma protocol is a life-saving procedure in a physician-staffed emergency medical system with best survival at 24 h and 90 days after penetrating trauma and/or in the presence of SOL. The success of rescue seems to mainly depend on non-technical skills such as prompt decision-making and effective teamwork. The era of endovascular resuscitation, introduced by the use of REBOA, would restrict the indications of EDT to severe thoracic trauma and/or cardiac arrest [29].

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Declarations

Conflict of interest The authors do not have any conflicts of interest related to this manuscript.

Ethics approval Our prospective registry of severe trauma patients has been registered by the Commission. Nationale de l'Informatique et des Libertés (CNIL) under number 2002878v0 reports anonymised information. This research study was conducted retrospectively from data obtained for clinical purposes. Ethical approval was waived by the local Ethics Committee and the French Society for Thoracic and Cardiovascular Surgery (FSTCVS) under registration number 2019–18 in view of the retrospective nature of the study and all the procedures being performed as part of routine care. This research has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Specific national laws have also been observed.

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