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Prehospital emergency finger thoracostomy in compensated obstructive shock: Benefits and outcomes

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ABSTRACT

Background: Emergency finger thoracostomy (EFT) has been implemented in several European prehospital settings for intubated and ventilated patients with chest injuries. The indication for intervention in cardiac arrest and peri-arrest situations is clear. EFT may also be applicable in ventilated but macrohemodynamically compensated patients. This study aims to help prehospital providers understand the benefits and applicability of EFT.

Patients and methods: A retrospective analysis was conducted consisting of 114 EFT cases over 53 months. All chest-injured patients had suspected intrapleural pathology and potential compensated obstructive shock state. Two groups were compared: I. Positive clinical finding after EFT: audible air (pneumothorax (PTX)) and/or blood (hemothorax (HTX)) ($n = 85$); II. Negative clinical finding: no audible air and/or blood escaping during the procedure ($n = 29$). The primary endpoint was the effect of EFT on the physiologic parameters. The secondary endpoint was the association between intrathoracic pathology observed during EFT and the physiologic effect.

Results: In 75 % of all cases, after EFT, intrapleural pathology was detectable by on-site physical examination. After EFT SpO2 levels increased from 89.6 % (SD 10.7) to 94.9 % (SD 6.7) ($p < 0.001$). The other physiological parameters did not change significantly ($p = 0.346$ or higher). In subgroup analysis, there were appreciable increases in SpO2 for those with PTX or PTX with HTX, that were not seen in those with HTX alone or those with negative clinical findings ($p < 0.001$). No significant adverse effects of EFT were noted during the prehospital phase or in the hospital follow-up period.

Discussion: EFT performed in ventilated patients with suspected compensated obstructive shock (and stable macrohemodynamic) resulted in audible air and/or blood escape and an improvement in oxygenation if PTX or PTX with HTX were the underlying pathology.

Conclusion: Performing an EFT should be considered not only for deteriorating obstructive shock state but also for potentially compensated shock. Even with diagnostic uncertainty, the benefits of an EFT may outweigh the risks.

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Background

Chest injuries represent the third most prevalent cause of death among severely injured patients [1]. These injuries account for nearly a quarter of all trauma-related fatalities [2]. Damage to chest wall structures, such as the ribs, sternum, and/or lung parenchyma, and mediastinal organs, significantly affects survival outcomes [3]. "Scoop and run" and "stay and play" are two well-established approaches in the prehospital care of severely injured patients, each offering distinct advantages and disadvantages [4]. Life-saving interventions that were previously reserved for in-hospital care are now available to prehospital health care providers (blood transfusion, chest cavity decompression, surgical airway, endovascular intervention), with significant changes in these paradigms. Various factors determine the optimal treatment at the scene and en-route in the modern prehospital setting: the combination of injuries, the transport platform, and the capability and equipment of the clinical crew. In cases of penetrating trauma, quality survival depends on early surgical treatment to control bleeding. In blunt trauma, appropriate on-site care is the most beneficial, including securing a patent airway and circulatory stabilization. One principal aim is to avoid secondary damage. There are cases of head injuries for whom appropriate on-site treatment could be also definitive [5]. Often patient injury patterns are not straightforward and have a more complex combination of injuries which require appropriate on-scene procedures as well as urgent transport. The prehospital environment is not an optimal setting for the identification of minor changes in organ perfusion or fine hemodynamic measurements. There is a significant level of heterogeneity in the relevant literature data with low levels of evidence for distinct procedures, such as optimal prehospital management for possible intrapleural pathology like PTX and/or HTX. The increasing popularity of emergency finger thoracostomy challenges the formerly dominant tube thoracostomy - preferred by many first responder services - and the large bore needle decompression typically performed by combat medics [6,7]. The expected beneficial effect of EFT on an intubated and ventilated patient is overshadowed by the reported overall complication rate of 10–12 % [8]. Several studies have assessed changes in vital parameters following on-site intervention in tension PTX and/or HTX. The significant change of vital parameters reflected the causal treatment of uncompensated obstructive shock. When the lung collapses as a result of intrapleural pathology, the ventilation-perfusion (V/Q) ratio shifts in the direction of perfusion. If this shift is large enough, it may be reflected in macro-hemodynamic parameters [9]. Based on the physiological effect, we can distinguish between simple and tension PTX (tPTX) [10]. Due to the increase in intrathoracic pressure, the tPTX leads to the development of obstructive shock, and intermittent positive pressure ventilation (IPPV) accelerates this process. With large HTX, hypovolemic shock may also be present. HTX can additionally lead to obstructive shock, but this is less common [11]. Obstructive shock caused by tPTX is a process that begins with compensated shock. This initial stage progresses to uncompensated shock, characterized by significant deviations in macro-hemodynamic parameters [12,13]. There is limited evidence to guide decision-making for implementing prehospital EFT in patients with signs of pneumothorax but without shock in order to prevent further deterioration. As the obstructive shock is in the compensated phase, adaptation of the circulatory system leads to progressively increasing systemic vascular resistance and a consequential decrease in organ perfusion. Circulatory shock is always progressive and it shifts continuously from "stable" macrohemodynamic parameters (but impaired microcirculation) to an unstable phase [14]. The specific subgroup of such patients with potential compensated obstructive shock caused by intrapleural pathology falls in a "gray zone" of decision-making. Skepticism about the necessity of intrapleural pressure relief in these cases is challenging the acceptance of EFT as a standard operating procedure.

Available literature demonstrates that EFT is an effective and safe procedure for tension PTX in uncompensated shock patients with clearly impaired macrohaemodynamics [7,15–17]. The goal of this study was to examine the effects of EFT on macrohemodynamically stable, positive pressure ventilated patients with suspected PTX and/or HTX. Hypothetically, the observed changes would reflect effect of pressure relief in compensated obstructive shock patients. The results based on this population could help to better understand the risk-benefit ratio of EFT in stable blunt chest trauma patients.

Patients and methods

Study design

The study is a retrospective observational study of 114 cases that received treatment between May 1, 2018, and November 1, 2022, administered by the Hungarian Helicopter Emergency Medical Service (HEMS). Hungarian HEMS documentation is maintained in its own computer system (HEMSDOK), with automatic vital parameter and ultrasound image integration. This is an automatic process with data uploaded at the end of each case. All case documentation was reviewed and validated by a third party who is also a HEMS physician. The documentation for quality control is randomly distributed between 10 HEMS consultants who are independent of the treating crew. All relevant case notes pertaining to post-mission procedural reports and hospital handover details, including the study, received ethical approval (IV/2746-3/2022/EKU, ETT TUKEB).

The EQUATOR (Enhancing the Quality and Transparency of Health Research) network and STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement were used for the study design.

Study settings

The HEMS in Hungary is an integral part of the nationwide first responder ambulance network, encompassing the entire country (9.7 M individuals, 93.026 km2), and 7 bases on daytime duty with Airbus EC-135 helicopters. The HEMS Crew consists of 3 people: a pilot, a paramedic, and a physician. The majority of doctors have specialized qualifications in anesthesiology, intensive therapy, or emergency medicine, and there are also specialist qualifications in trauma, orthopedics and general surgery. More than half of the HEMS missions are for major trauma. The average flight time is 21 min to the scene, and 17 min to the local Level 1 Trauma Center. Transport by ground is significantly slower and for this reason, these patients are usually transported by helicopter. HEMS makes treatment recommendations and guides decision-making utilizing its own Standard Operating Procedures (SOP). Emergency on-site thoracostomy is a standard procedure for mechanically/positive pressure ventilated patients requiring chest decompression [18–21]. This EFT procedure aligns with the Advanced Trauma Life Support (ATLS) chest decompression guidelines, with the exception of inserting a chest drain into the thoracostomy cavity [22,23]. All physicians of the Hungarian HEMS receive medical training, which includes the regular implementation of EFT. Ultrasounds are available on all helicopters, but the skill levels of the providers vary significantly. Ultrasounds support the decision-making process as positive findings (the absence of sliding, lung point) establish a relative indication for EFT (Table 1). It is an important attribute of the EFT standard operational procedure that ultrasound alone cannot be used to rule out EFT if either absolute or relative indications are present. All procedure-related early adverse reactions (bleeding, position error, occlusion) are registered in HEMSDOK and reviewed by multiple third-party HEMS physician consultants independently of the treating crew.

In Hungarian Level 1 Trauma Centers, seriously injured patients are cared for in a similar way. There is no national SOP, but most of hospitals follow the recommendations of the European Trauma Course (ETC). After admission, patients with EFT usually receive antibiotic prophylaxis and chest tube insertion into the EFT hole. Hospital follow-

Table 1
Indications for the emergency finger thoracostomy (EFT; Hungarian HEMS protocol).

1. Traumatic cardiac arrest.
2. Hemodynamically unstable. ventilated casualty suspected tPTX (tension PTX).
3. Hemodynamically stable. ventilated casualty with whom high suspicion of PTX:
   a. surgical emphysema
   b. ultrasound proven
   c. penetrating chest trauma
   d. extensive flail chest
4. A hemodynamically stable. ventilated casualty in whom PTX is possible based on any of the following risks of developing tPTX
   a. absent breath sound/side difference despite proper tracheal tube position and patency
   b. a combination of relevant injury mechanisms and extensive chest wall damage
   c. serial palpable rib fractures

Groups 1 and 2: absolute indication for EFT
Groups 3 and 4: relative indication – judged by the individual attendant (HEMS physician)

up was limited. Many of the patients were documented as an "unknown patient" (John/Jane Doe) in the prehospital phase and consequently for a few days during the hospital stay. The follow-up was unreliable/ impossible after proper identification and name change in the documentation.

The selection criteria for inclusion in this study include the following:

- Over 18 years of age
- Blunt chest trauma and potential intrapleural pathology (PTX and/or HTX)
- EFT on one or both sides (s) of the chest according to criteria 3 and 4 in Table 1
- Stable hemodynamics identified by the use of full dose ketamine induction at the Rapid Sequence Intubation (RSI) (2 mg/kg) [24–26]
- The time window between RSI and thoracostomy was <5 min [27, 28]
- No need for circulation-supporting medication

Stable hemodynamics was defined as SBP > 90 Hgmm, MAP > 65 Hgmm, $P < 140$/min.

The exclusion criteria in this study include the following:

- Traumatic Cardiac Arrest (TCA)
- Uncompensated obstructive shock, with macro-hemodynamic parameter changes (SBP < 90 Hgmm, MAP < 65 Hgmm, $P > 140$/min)

During EFT, one of the four outcomes was registered: 1) pneumothorax (PTX) (clearly noticeable air escape during EFT); 2) hemothorax (HTX),(clearly noticeable blood escape); 3) PTX and HTX combined; and 4) negative physical findings (no noticeable air/blood escaped during the procedure).

Unilateral and bilateral chest pathologies were accounted for separately.

The prehospital indications representative of EFT are listed in Table 1.

The presence of one of the signs listed in Table 1 is adequate to form an indication (absolute or relative) for EFT in the study and in the standard operational procedure as well. Table 1 is a translation of the HEMS SOP update version at this time. These physical signs serving the basis of suspicion for PTX and/or HTX formed the decision for all patients uniformly. The following parameters were registered: Pulse (P), oxygen saturation (SpO2), blood pressure: systolic (SBP), mean arterial pressure (MAP), and end-tidal carbon-dioxide (etCO2). All patients had a set of four measurements as a block of data: prior to and following RSI and prior to and following EFT. To compare changes before and after EFT, the last measurement before the intervention and the 3-minute post-intervention parameters were used. More than a 10 % change in the parameters was considered statistically significant.

For statistical analysis, TIBCO Statistica 14.0 was used. Paired *t*-tests were performed on the entire sample to assess parameter changes. In the analysis, group D (control group) with negative chest findings served as the cohort group for misdiagnosis, against which changes in groups A, B, and C were compared. Univariate one-way ANOVA was conducted to compare the means of groups, followed by Tukey's HSD post-hoc test. The cross tabulation in Table 7 was analysed using the chi-squared test with Yates' continuity correction. The significance level was set at $p < 0.05$.

According to our hypothesis, alteration of vital signs may reflect the effect of EFT on resolution of compensated obstructive shock in macrohemodynamically stable blunt chest trauma patients. In this group of patients, the effect of intrapleural pathology could be verified with certainty if the intervention were withheld and the macro-hemodynamic parameters deteriorated. However, this approach could be harmful to patients, and might be considered unethical. The cabin of the helicopter is not suitable to perform EFT during flight and the patient evacuation en-route usually takes significant time. According to Hungarian HEMS SOP, EFT should be performed before the patient is immobilized in the cabin. According to our nomenclature, obstructive shock with changes in macro-hemodynamic parameters is considered uncompensated shock.

The goal of this study was to examine the effects of EFT on macrohemodinamically stable and positive pressure ventilated patients with suspected PTX and/or HTX. Our study focused on the "gray zone" of patients whose condition, based on physical examination, indicated possible compensated obstructive shock due to PTX.

The primary endpoint was the vital parameter change based on the intrathoracic pathology. The secondary endpoint was the association between intrathoracic pathology observed during EFT and the physiologic effects.

Results

During the study period, 5350 HEMS trauma missions were completed, in which EFT was performed in 384 cases (7.2 %). 114/384 patients were eligible for this study with suspected intrapleural pathology and potential compensated obstructive shock state.

Demographics: male (74/114), female (40/114), average 42 (SD 12) years. Mechanism/ cause of injury: road traffic accident (n:67), fall from height (>5 m; n:17), and industrial accident (n:30). The prehospital National Advisory Committee for Aeronautics score (NACA) was 4 or 5 in all cases. NACA score 4 means potential life-threatening disorder, while NACA score 5 means acute life-threatening disorder [29]. 49/114 patients underwent unilateral interventions, and 65 bilateral interventions were performed (179 EFT in 114 patients). The above-detailed EFT procedural outcomes served as criteria for inclusion into one of the four study groups (Fig. 1.).

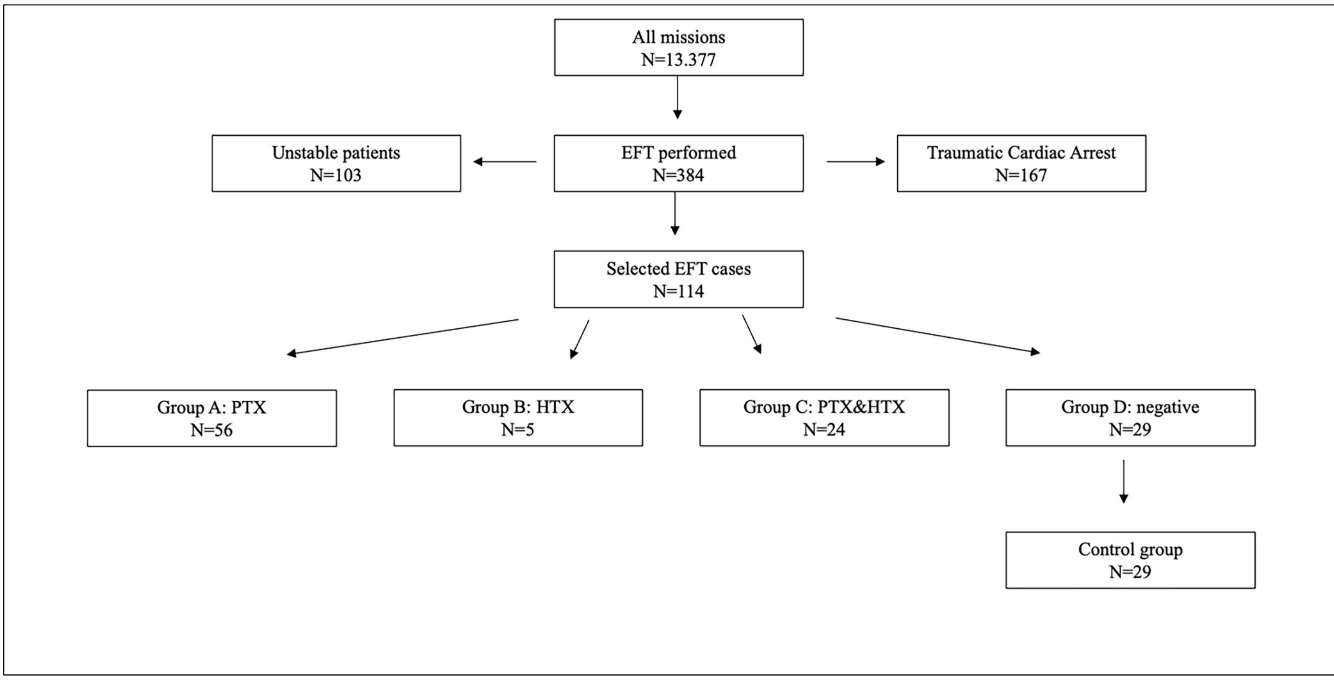

Fig. 1. Study groups.

Group A: ($n = 56$); PTX on one or both sides and proven by physical findings (The chest pressure is sufficiently positive for the turbulence of the escaping air to be audible in prehospital setting).
Group B: ($n = 5$); HTX on one or both sides and proven by physical findings without PTX (intrapleural blood escaping during the procedure).
Group C: ($n = 24$); PTX with HTX combined on one or both sides or PTX on one side and HTX on the other side (audible air and blood escaping during the procedure).
Group D: ($n = 29$); negative clinical findings (procedure performed based on strong clinical suspicion of intrapleural pathology and compensated obstructive shock, however no audible air and/or blood escaped during the procedure. No audible air escaping does not exclude the possibility of PTX with minimal or no pressure elevation in the intrapleural space).

On-site physical diagnosis of threatening obstructive shock heralded by the escape of a significant amount of air and/or blood during the procedure was correct in 75 % of all cases (85/114).

There were patients for whom vital parameters were missing, or the change could not be calculated due to the lack of pre-intervention or post-treatment measures. The descriptive statistics are shown in Table 2.

The parameters were examined by paired *t*-test on the whole sample ($n = 114$) prior to and following EFT. Most of them did not change significantly: HR ($p = 0.346$), SBP ($p = 0.449$), MAP ($p = 0.956$), etCO2 ($p = 0.950$). The sole exception was in case of SpO2, in which a significant increase was detected ($p < 0.001$) on the whole sample. The changes are indicated in Table 2, and the statistical analyses are shown in Table 3.

To further investigate the parameter changes among the subgroups, one-way ANOVA tests were performed. The results indicated that only SpO2 showed a significant difference in variability among the subgroups ($p = 0.005$). Pairwise Tukey HSD revealed a significant difference in SpO2 changes between group C (PTX with HTX) and group D (negative finding) ($p = 0.003$), as well as between group A (PTX) and group D ($p = 0.035$). (Tables 4,5)

We investigated the effect of PTX and HTX on either side as independent factors using univariate ANOVA for each parameter, finding significant deviation from the control only in the case of SpO2 shift among PTX patients (with or without HTX, $p = 0.001$). Furthermore, this method was used to examine the synergistic effects of PTX and HTX on parameter changes, but the test did not reveal any interaction (Table 6).

We created a crosstabulation showing the distribution of SpO2 shifts with a 10 % upper cutoff among patients with (groups A, C) or without (groups B, D) PTX (independent of HTX status). We did not find patients with over 10 % decrease of SpO2. The Yates corrected Chi-square with $p = 0.002$ underlined the suspected SpO2 change associated with PTX, shown in Table 7.

There were no reported or observed procedure-related early adverse reactions (bleeding, position error, occlusion). The in-hospital follow-up was available in 70/114 cases. The average follow-up period following admission was 15 days (SD 6 days). Among these cases, septic condition developed in 7/70 patients. Hospital examinations did not confirm thoracic empyema in any of the septic patients.

Discussion

Cardiopulmonary arrest or blunt chest trauma presenting with uncompensated shock and macrohemodynamic deterioration offer clear indications for the EFT procedure. These critical situations decisively challenge first responders because of narrow time windows and highly limited diagnostics. The goal of this study was to examine the effects of EFT on macrohemodinamically stable and positive pressure ventilated patients with suspected PTX and/or HTX. Our study focused on the "gray zone" of patients whose condition, based on physical examination, indicated possible compensated obstructive shock due to PTX.

Following EFT, intrathoracic pressure relief was detected as certain physiological parameters improved. The rate of normalization of the parameters depended on the kinetics of pressure change. In our blunt chest trauma cohort, no effect on SBP, MAP, and/or etCO2 was detected. Additionally, no differences were observed between the positive clinical findings groups (Groups A, B, and C) and the negative clinical findings group (Group D). It is possible that changes in the hemodynamics (cardiac output, systemic vascular resistance, preload) as compensated shock gradually resolved were not reflected in macro-hemodynamic parameters.

Table 2
Descriptive statistics.

	all	group A (PTX only)	group B (HTX only)	group C (PTX and HTX)	group D (negative)
Count	114	56	5	24	29
Percent	100 %	49 %	4 %	21 %	25 %

Last value before thoracostomy

	all			group A (PTX only)			group B (HTX only)			group C (PTX and HTX)			group D (negative)		
	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev
HR	114	120.68	25.25	56	122.38	26.10	5	105.60	16.68	24	122.46	29.89	29	118.55	20.20
SpO2	108	89.63	10.71	51	90.78	9.96	5	96.20	4.76	24	84.71	13.15	28	90.57	9.35
SBP	105	110.71	32.93	52	112.19	33.16	4	117.50	41.73	22	112.14	35.39	27	105.70	30.49
MAP	105	85.91	25.19	52	85.88	24.85	4	90.75	31.22	22	87.18	27.54	27	84.22	24.36
etCO2	113	34.24	8.69	56	36.04	9.26	4	32.75	2.99	24	32.63	7.81	29	32.31	8.35

First value after thoracostomy

	all			group A (PTX only)			group B (HTX only)			group C (PTX and HTX)			group D (negative)		
	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev
HR	114	122.39	23.41	56	125.50	24.96	5	118.80	24.24	24	118.83	25.43	29	119.97	18.25
SpO2	108	94.92	6.69	51	97.14	5.02	5	96.00	5.66	24	93.63	6.57	28	91.79	8.24
SBP	104	112.64	29.17	52	114.42	25.38	4	120.50	40.32	23	110.78	30.19	25	109.40	34.83
MAP	104	86.02	22.43	52	87.38	19.36	4	88.50	27.09	23	86.00	21.34	25	82.80	28.95
etCO2	114	34.21	7.28	56	35.45	6.71	5	34.40	3.51	24	34.25	7.00	29	31.76	8.61

Parameter change (value after - value before)

	all			group A (PTX only)			group B (HTX only)			group C (PTX and HTX)			group D (negative)		
	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev	Valid N	Mean	Std.Dev
HR	114	1.71	19.31	56	3.13	16.99	5	13.2	16.2	24	−3.63	23.17	29	1.41	20.19
SpO2	107	5.22	8.19	50	6.22	7.66	5	−0.2	1.3	24	8.92	11.23	28	1.21	3.57
SBP	100	1.71	22.47	51	2.35	24.16	4	3.0	7.6	22	0.00	20.96	23	1.70	22.68
MAP	100	0.11	19.69	51	1.49	20.01	4	−2.3	4.3	22	−0.59	18.55	23	−1.87	22.20
etCO2	113	−0.04	5.98	56	−0.59	6.96	4	1.5	2.4	24	1.63	4.91	29	−0.55	4.93

At least 10 % change of parameter value

	all			group A (PTX only)			group B (HTX only)			group C (PTX and HTX)			group D (negative)		
	>10 % decrease	no sign. change	>10 % increase	>10 % decrease	no sign. change	>10 % increase	>10 % decrease	no sign. change	>10 % increase	>10 % decrease	no sign. change	>10 % increase	>10 % decrease	no sign. change	>10 % increase
HR (valid N)	16	70	28	6	36	14	0	2	3	6	12	6	4	20	5
Percent	14 %	61 %	25 %	11 %	64 %	25 %	0 %	40 %	60 %	25 %	50 %	25 %	14 %	69 %	17 %
SpO2 (valid N)	0	82	25	0	35	15	0	5	0	0	15	9	0	27	1
Percent	0 %	94 %	22 %	0 %	63 %	27 %	0 %	100 %	0 %	0 %	63 %	38 %	0 %	93 %	3 %
SBP (valid N)	19	51	30	11	24	16	0	3	1	4	10	8	4	14	5
Percent	17 %	45 %	26 %	20 %	43 %	29 %	0 %	60 %	20 %	17 %	42 %	33 %	14 %	48 %	17 %
MAP (valid N)	29	42	29	17	16	18	0	4	0	6	9	7	6	13	4
Percent	25 %	37 %	25 %	30 %	29 %	32 %	0 %	80 %	0 %	25 %	38 %	29 %	21 %	45 %	14 %
etCO2 (valid N)	19	74	20	12	32	12	0	3	1	1	18	5	6	21	2
Percent	17 %	65 %	18 %	21 %	57 %	21 %	0 %	60 %	20 %	4 %	75 %	20 %	20 %	72 %	8 %

Table 3
Paired *t*-tests with parameter changes (value after - value before) on whole sample.

	N	Diff.	Std.Dev. Diff.	t	df	p	Confidence −95 %	Confidence +95 %
HR	114	−1.711	19.311	−0.946	113	0.346	−5.294	1.873
SpO2	**107**	**−5.215**	**8.185**	**−6.590**	**106**	**<0.001**	**−6.784**	**−3.646**
SBP	100	−1.710	22.473	−0.761	99	0.449	−6.169	2.749
MAP	100	−0.110	19.686	−0.056	99	0.956	−4.016	3.796
etCO2	113	0.035	5.985	0.063	112	0.950	−1.080	1.151

Table 4
Univariate ANOVA comparing means of parameter changes among groups A/B/C/D.

	HR change				
	SS	df	MS	F	p
Intercept	677.530	1	677.533	1.832	0.179
Groups A/B/C/D	1457.860	3	485.954	1.314	0.274
Error	40,681.580	110	369.833		
Total	42,139.450	113			
	SpO2 change				
	SS	df	MS	F	p
Intercept	877.169	1	877.169	14.744	**<0.001**
Group A/B/C/D	974.128	3	324.710	5.458	**0.002**
Error	6127.928	103	59.494		
Total	7102.056	106			
	SBP change				
	SS	df	MS	F	p
Intercept	138.570	1	138.569	0.267	0.607
Group A/B/C/D	92.070	3	30.691	0.059	0.981
Error	49,906.520	96	519.860		
Total	49,998.590	99			
	MAP change				
	SS	df	MS	F	p
Intercept	28.920	1	28.923	0.073	0.788
Group A/B/C/D	220.370	3	73.456	0.185	0.906
Error	38,147.420	96	397.369		
Total	38,367.790	99			
	etCO2 change				
	SS	df	MS	F	p
Intercept	11.442	1	11.442	0.319	0.573
Group A/B/C/D	100.507	3	33.502	0.934	0.427
Error	3911.351	109	35.884		
Total	4011.858	112			

Table 5
Tukey HSD post-hoc test on average changes of SpO2.

	none	PTX	HTX	PTX with HTX
none		0.035	0.982	0.003
PTX	**0.035**		0.292	0.497
HTX	0.982	0.292		0.083
PTX with HTX	**0.003**	0.497	0.083	

According to our primary hypothesis, the oxygenation (SpO2) increased significantly after EFT compared to the pre-EFT value. Examining each subgroup, the change was significant in the presence of PTX and PTX with HTX intrathoracic pathologies. Pairwise Tukey HSD analysis revealed a significant deviation in SpO2 changes between the PTX and the control group (negative findings), as well as between the PTX with HTX group and the control cohort. During crosstabulation and Chi2-test, examining the presence of PTX independently of the presence of HTX, we found a significant correlation when considering an increase greater than 10 %.

The kinetics of alteration in intrapleural pressure caused by PTX

Table 6
Univariate ANOVA comparing parameter change in case of PTX on any side, HTX on any side and (PTX on any side) x (HTX in any side).

	HR change				
	SS	df	MS	F	p
Intercept	677.530	1	677.533	1.832	0.179
PTX on any side	776.940	1	776.944	2.101	0.150
HTX on any side	86.270	1	86.268	0.233	0.630
(PTX on any side) x (HTX on any side)	1168.650	1	1168.651	3.160	0.078
Error	40,681.580	110	369.833		
Total	42,139.450	113			
	SpO2 change				
	SS	df	MS	F	p
Intercept	877.169	1	877.169	14.744	**<0.001**
PTX on any side	670.660	1	670.661	11.273	**0.001**
HTX on any side	5.530	1	5.530	0.093	0.761
(PTX on any side) x (HTX on any side)	56.829	1	56.829	0.955	0.331
Error	6127.928	103	59.494		
Total	7102.056	106			
	SBP change				
	SS	df	MS	F	p
Intercept	138.570	1	138.569	0.267	0.607
PTX on any side	15.310	1	15.307	0.029	0.864
HTX on any side	3.070	1	3.067	0.006	0.939
(PTX on any side) x (HTX on any side)	37.310	1	37.306	0.072	0.789
Error	49,906.520	96	519.860		
Total	49,998.590	99			
	MAP change				
	SS	df	MS	F	p
Intercept	28.920	1	28.923	0.073	0.788
PTX on any side	70.250	1	70.254	0.177	0.675
HTX on any side	16.900	1	16.900	0.043	0.837
(PTX on any side) x (HTX on any side)	8.070	1	8.067	0.020	0.887
Error	38,147.420	96	397.369		
Total	38,367.790	99			
	etCO2 change				
	SS	df	MS	F	p
Intercept	11.442	1	11.442	0.319	0.573
PTX on any side	0.022	1	0.022	0.001	0.980
HTX on any side	52.903	1	52.903	1.474	0.227
(PTX on any side) x (HTX on any side)	0.077	1	0.077	0.002	0.963
Error	3911.351	109	35.884		
Total	4011.858	112			

and/or HTX did not have significant impact on macro-hemodynamic parameters prior to RSI in the examined chest injured population. Consequently, the injured had stable hemodynamics, and no critical oxygenation disorders could be identified. Nevertheless, a noticeable improvement was observed post-EFT, significantly affecting SpO2 in many cases. The strength of the correlation between clinical findings and the increase in SpO2 suggests that the presence of PTX and PTX-HTX combined pathology exerted the most substantial influence.

Table 7
Crosstabulation and chi-squared test with Yates' continuity correction on (PTX on any side) x (10 % SpO2 change).

	no or <10 % increase in SpO2	>10 % increase in SpO2
PTX on any side (groups A. C)	32	1
no PTX observed (groups B. D)	50	24
Yates corrected Chi-square	$\chi = 9.44$	$p = 0.002$

The audible sound when the air leaves the chest is caused by turbulent flow. Theoretically, in case of minimal outflow intensity, there may be weak turbulence that cannot be heard in the noisy prehospital environment. The EFT is performed in the midaxillary line, so in a supine position, there is an amount of fluid that cannot leave due to gravity despite the driving force of the ventilated lungs.

Pulmonary contusion is common with blunt chest trauma [30]. As a consequence of extensive acute lung injury, the respiratory surface and the lung's reserve capacity are diminished. PTX, HTX, and pulmonary contusion can synergically reduce the lung's ability to engage in efficient gas exchange and can contribute to V/Q mismatch.

The recent emergence of non-intubated thoracic surgery (NITS) is a strong argument and proof regarding the pressure tolerance of the intrapleural space. Thoracic surgery could be considered a form of artificial trauma for the patient. The relationship between the intrapleural pressure change and the hemodynamic effect shows continuity [31].

To effectively perform EFT, the provider must have full 360 degrees access around the patient and access to the thorax. During transport of the injured patient to the hospital by ground, it is easy to stop and take the patient out of the ambulance to perform the intervention. Landing by helicopter and removing the patient is much more complicated and takes more time (depending on the terrain and on the on-board stretcher system, it can take 3–6 min). There is an ongoing debate about the safest operational procedure but these circumstances clearly favor on scene EFT. Here we provided evidence for the beneficial physiological effects of EFT in "gray zone" patients. There is sufficient previous evidence that EFT is a safe and effective procedural method. The cited evidence and the penetration of the procedure into guidelines are reassuring. This study provides evidence for better understanding of the physiological consequences of EFT performed in the study population, if the EFT is carried out based on relative rather than absolute indications. The early and late complication rate of EFT did not differ in the study setting from those presented in the literature.

The first commandment of medicine, "nil nocere" (do not cause harm) was upheld with our results reflecting the safety of the procedure. All of the examined EFTs were free of early (prehospital) complications, clearly demonstrating the effectiveness of regular medical training of the staff. Failures associated with tube thoracostomy, such as malposition, occlusion, parenchymal, and vessel injury were all avoided in this study [32,33]. All case documentation was reviewed, quality controlled, and validated by a third party HEMS consultant and the absence of early complications was confirmed. Hospital follow-up was successful in 61 % of the cases. A septic condition was described in 7/70 patients. Because these patients also had other injuries, no clear association between EFT and sepsis could be demonstrated. Hospital examinations did not identify thoracic empyema and thoracostomy wound infection. The ability of this study to detect safety outcomes was limited by the relatively low hospital follow-up rate.

Conclusion

The study supports the benefit of EFT as an emergency procedure in patients with a strong suspicion of intrapleural pathology and possible compensated obstructive shock. The lack of evidence for PTX and/ or HTX during the procedure does not discredit the decision to perform EFT in intubated thoracic trauma patients within the prehospital setting. EFT is an appropriate technique to prevent further clinical deterioration from thoracic injury. The "err on the safe side" policy seemingly serves the interest of the patients in this "gray zone" of severe blunt chest injuries.

Limitations

This observational study relied on physical finding reports without objective imaging. The degree of pre-procedural PTX and the amount of hemothorax were measured by the rule of thumb. Impending intrapleural pathology was judged by clinical experience supported by circumstantial evidence and basic physiological parameters. As this is a case series study, there was no non-EFT comparator group; the number of co-factors and various parameters made it impossible to create a reliable pool of comparators. From the point of view of patient safety, it would not be ethical to create a control group where EFT is not performed. During flight, in the small cabin of the helicopter, it is not possible to provide an immediate solution to a deterioration of the patient's condition. Adequate follow-up for complications was limited. The size of the hospital follow-up was a limitation in terms of late complications. The role of ultrasound for clinical decision making was not determined because of insufficient documentation.

Ethics statement

The authors declare that their work was carried out under ethical approval. The Hungarian Scientific Ethics Committee approved the ethical approval. Approval number: IV/2746-3/2022/EKU, ETT TUKEB. The original decision approval is attached.

Generative AI in scientific writing

No AI software was used for this research or article writing.

CRediT authorship contribution statement

David Sutori: Writing – original draft, Resources, Methodology, Data curation, Conceptualization. **Laszlo Sandor Erdelyi:** Writing – review & editing. **Imre Uri:** Software, Data curation. **Laszlo Zavori:** Writing – review & editing. **Luca Anna Ferkai:** Formal analysis, Data curation. **Laszlo T. Hetzman:** Methodology, Data curation. **Robert Gebei:** Resources, Data curation. **Gabriella Kecskes:** Writing – original draft. **Tamas F. Molnar:** Writing – original draft, Validation, Supervision.

Declaration of competing interest

The authors declare no conflicts of interest.

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