Emergency Abdominal Surgery Outcomes of Critically Ill Patients on Extracorporeal Membrane Oxygenation: A Case-Matched Study with a Propensity Score Analysis

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Disclosure information: authors have no conflicts of interest to disclose.

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Brief title: Emergency abdominal surgery outcomes and ExtraCorporeal Membrane Oxygenation

Key Words: digestive surgery extracorporeal membrane oxygenation; venoarterial; venovenous; noncardiac surgery; bleeding; hemostasis

Manuscript word count: 3118

ABSTRACT

Background: Extracorporeal membrane oxygenation (ECMO) induces coagulation disorders increasing the risk of bleeding during invasive procedures. We aimed to describe the outcomes of critically ill ECMO patients undergoing emergency abdominal surgery compared to nonECMO patients.

Study Design: Retrospective case-matched single-center study with propensity score analysis in a tertiary ICU. All patients who underwent abdominal surgery were included.

Results: From 2006 to 2014, 77 patients admitted in our ICU underwent emergency abdominal surgery, 35 were on ECMO. Surgery indications were comparable for ECMO and nonECMO patients: mostly intestinal ischemia (42%) and cholecystectomy (25%). Postoperative bleeding was significantly more frequent in ECMO group *vs.* nonECMO: 77% vs 40% transfused, with medians of 13 (6–22) vs. 3 (0–5) packed red blood cell; 9 (3–17) vs 0 (0–4) fresh-frozen plasma and 12 (3–22) vs 0 (0-8) platelet units ($p<0.001$ for all items). Reintervention for haemorrhage was required in 20% vs 2% respectively, $p = 0.02$. At multivariable analysis, ECMO was strongly associated with bleeding (OR, 5.6 [95% CI, 2.0–15.4]; $p = 0.001$). ICU mortality was higher for ECMO-treated patients (69% vs. 33%; $p = 0.003$) but perioperative mortality remained comparable between groups (11% vs. 12%, NS). More frequent and severe bleeding was confirmed for highly comparable ECMO and nonECMO patients (21 each), propensity score-matched to be ECMO-implanted.

Conclusions: Abdominal surgery procedures on ECMO-treated patients are associated with a higher risk of haemorrhage compared to nonECMO ICU patients. Further studies are needed to optimize ECMO-patient management during such interventions.

ABBREVIATIONS

ARDS, acute respiratory distress syndrome

ECMO, extracorporeal membrane oxygenation

PRBCs, packed red blood cell units

SAPS, Simplified Acute Physiology Score

SOFA, Sepsis-Related Organ-Failure Assessment

VA-ECMO, venoarterial-extracorporeal membrane oxygenation

VV-ECMO, venovenous-extracorporeal membrane oxygenation

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is increasingly used as rescue therapy during major cardiac failure or acute respiratory distress syndrome (ARDS), (1–3) but remains associated with major complications. ECMO-treated patients are at high-risk of haemorrhage during invasive procedures, due to major coagulation disorders induced by the patient's critical state and the device itself. (4–6) In this context, emergency surgery, when needed, is perceived as extremely detrimental. The outcomes of ECMO-assisted patients undergoing noncardiac surgery have only been poorly described to date. More specifically, no study focused on abdominal surgery in this setting. This may be of particular interest in order to improve peroperative management of these patients.

The aim of the present case-matched study, using a propensity score analysis, was to assess the outcomes of patients on ECMO who required emergency abdominal surgery, and to compare the postoperative outcomes with those of nonECMO patients matched for initial severity.

METHODS

Patients and Data Collection

All our intensive care unit (ICU) patients who underwent emergency abdominal surgery between July 2006 and August 2014 were eligible for the study. Patients were screened from the operating room registry of the surgery department. Data were extracted from the computerized ICU charts. In accordance with our hospital's Institutional Review Board (Committee for the Protection of Human Subjects) ethical standards, informed consent for demographic, physiological and hospital-outcome data analyses was not required because this observational study did not modify existing diagnostic or therapeutic strategies.

ECMO Implantation and Management

All patients underwent Doppler echocardiography to evaluate hemodynamic status before ECMO implantation. Venoarterial-ECMO (VA-ECMO) was indicated for refractory cardiogenic shock, defined as evidence of tissue hypoxia (e.g., extensive skin mottling or elevated blood lactate) associated with low cardiac index (<2.2 L/min/m^2), despite infusion of high catecholamine dose and adequate fluid loading. (7) Venovenous-ECMO (VV-ECMO) was indicated for ARDS refractory to conventional treatment. (3)

Management of ECMO-implanted patients in our ICU was described previously. (8,9) All VA-ECMO devices were surgically inserted with femoral–femoral 23F to 29F–15F to 18F cannulation. An additional 7F catheter was systematically inserted into the femoral artery to prevent leg ischemia. Pump speed was adjusted to obtain blood flow of 3.5–4.5 L/min. Patients were assessed daily for possible ECMO weaning using clinical and echocardiographic criteria, as previously described. (10) VV-ECMO was inserted percutaneously with femoral–jugular 25F to 29F–18F to 21F cannulation. Weaning was achieved as previously described. (9) Experienced perfusionists checked the circuit daily.

A 5000-IU heparin bolus was injected at ECMO initiation and intravenous (IV) unfractionated heparin was given to maintain the activated partial thromboplastin time (aPTT) ratio at 1.5–2 times normal. The heparin dose was adapted at least once daily. Heparin was stopped when bleeding occurred or the platelet count decreased significantly (< 50 G/L). (11) The membrane oxygenator was changed prophylactically when the platelet count decreased significantly (< 50 G/L), blood oxygenation declined sharply or significant hemolysis appeared. (12)

Abdominal Surgery

All procedures were performed by trained abdominal surgeons. Cholecystectomy used retrograde or anterograde (when pediculitis was too severe) techniques.

For small bowel or colon ischemia, the length of intestinal resection depended on the extension of ischemic lesions. The mesentery or mesocolon was ligated with a thermo-fusion instrument (Ligasure®, Covidien, Minneapolis, Minnesota, USA) and intestinal stoma were created with 3.0 Vicryl®. Bowel anastomoses when performed, used a 65 or 80 GIA® stapler (AutoSuture Company, United States Surgical Corporation, Norwalk, CT).

Outcome Definitions

The following definitions were applied:

Preoperative period: the 24 hours preceding surgery; immediate postoperative period: the 24 hours postsurgery; and late postoperative period: the time between the 24 hours postsurgery and ICU discharge or death; perioperative bleeding: the need of transfusion of at least three units of packed red blood cell units (PRBCs) per procedure and within the 72-hours postsurgery.

Statistical Analyses

Continuous variables, expressed as medians (1^{st}–3^{rd} interquartile range [IQR]), were compared with Mann–Whitney *U*-tests. Categorical variables, expressed as *n* (%), were compared with Fisher's exact test. For multivariable analyses of factors associated with perioperative bleeding, all those associated with the dependent variable in univariable analyses with $p < 0.2$ were included using a backward-stepwise logistic-regression model. For practical purposes, continuous variables were transformed into categorical variables, with the median as the threshold (except for the Sepsis-Related Organ-Failure Assessment (SOFA) score which was trichotomized). All potential explanatory variables included in the multivariable analyses were

subjected to a correlation matrix for analysis of collinearity and variables associated among one another were not included in the model. Thereafter, multiple backward-stepwise logistic-regression analyses eliminated variables with an exit threshold set at $p > 0.10$.

For sensitivity analyses, baseline characteristics of ECMO and nonECMO patients were matched by their propensity scores to receive ECMO (13). Baseline covariates (age, sex, body mass index, sepsis, underlying diagnosis, Simplified Acute Physiology Score (SAPS) II and SOFA score) were used to build an initial logistic-regression model predicting ECMO implantation. After calculating each patient's propensity score to be ECMO-implanted, ECMO recipients were matched (1:1) to nonECMO ICU patients for the analysis, without replacement, based on the propensity score log odds ("logit"). Using the estimated logits, a randomly selected ECMO patient was matched to the nonECMO patient with the closest estimated logit value with a maximum 20% difference between the two logits. Investigators were blinded to other patient data during the matching procedure.

Analyses were computed with SPSS v20 statistics package (IBM Corporation, Armonk, NY), Prism 4.0c software (GraphPad Software, La Jolla, CA), SAS v9.3 (SAS Institute Inc, Cary, NC) and R software (R foundation for statistical computing, Vienna, Austria), with $p < 0.05$ defining significance.

RESULTS

Study Population

Among 1166 ECMO-implanted patients during the study period, 35 (3%) required abdominal surgery (**Fig. 1**). The two main indications were digestive ischemia and acute cholecystitis in 15 and 8 patients respectively. The other indications are reported in **Supplementary Table 1**. Patients' demographic characteristics are given in **Table 1**. The cohort consisted predominantly of VA-ECMO patients implanted for cardiogenic shock, who required

secondary surgery for abdominal complications. Only 20% were admitted primarily for gastrointestinal disease. Patients were young and very severely ill, as reflected by the median SOFA score of 16 and the median SAPS II of 71 at admission. Forty-two nonECMO patients underwent abdominal surgery during the study period. They had the same underlying diagnoses and indications for surgery profiles as the ECMO-treated patients, but were older and slightly less severely ill.

Perioperative Management

Patients' preoperative status is described in **Table 2**. Both groups had comparable hemodynamic impairments. Notably, the ECMO group had thrombocytopenia and lower fibrinogenemia than nonECMO patients. Surgical characteristics are reported in **Table 2**. Surgery was predominantly cholecystectomy, digestive resection and stoma creation via laparotomy. A significantly higher percentage of ECMO patients (66%) experienced bleeding during surgery requiring transfusion than nonECMO patients (48%). Perioperative bleeding (defined as transfusion of > 3 PRBCs during the first 72-hours postsurgery) was significantly more frequent for ECMO-treated patients (74% vs 33%, $p < 0.001$).

Outcomes

ECMO patients' postoperative periods were marked by significantly more bleeding than nonECMO patients (**Table 3**), with 77% vs 40% receiving PRBC, fresh-frozen plasma or platelet units ($p < 0.001$ for all items). Reintervention for haemorrhage was significantly more frequent in the ECMO group (20%) than in the nonECMO group (2%; $p = 0.02$). Importantly, bleeding-complication rates were comparable for VA- and VV-ECMO-treated patients (**Supplementary Table 2**).

Perioperative mortality (<72-hours postsurgery) was comparable between groups (**Table 3**):

four patient in ECMO-treated group (three died of refractory multiorgan failure after cardiogenic shock with digestive ischemia, and 1 of hemorrhagic shock following abdominal necrosectomy for acute pancreatitis) and three in the nonECMO group (all with episodes of refractory multiorgan failure following cardiogenic shock with digestive ischemia, and two with secondary ventilator-associated pneumonia). Five (14%) ECMO-group patients' deaths were directly triggered by abdominal surgery complications (one with postoperative peritonitis, and four with hemorrhagic shock following bleeding at the surgical site) *vs.* one (2%) nonECMO patient (postoperative peritonitis) (p = 0.08). Finally, 24 (69%) ECMO-treated patients died in-ICU *vs.* 14 (33%) nonECMO patients (p = 0.003). ECMO-group deaths were distributed as follows: 10 of refractory multiorgan failure, five of hemorrhagic shock, four of ventilator-associated pneumonia, three without myocardial recovery and limitation of active therapeutics, one without pulmonary recovery and one of peritonitis. In the nonECMO group, refractory multiorgan failure accounted for seven in-ICU deaths, ventilator-associated pneumonia for two, absence of neurological recovery for two, peritonitis for one and hemorrhagic shock for two. ICU mortality reached 80% for ECMO patients treated surgically for digestive ischemia and 50% of patients undergoing cholecystectomy.

Factors Associated with Postoperative Bleeding

At univariable analysis, age, body mass index, SOFA score and ECMO implantation were associated with perioperative bleeding, whereas laparotomy was associated with a protective effect (**Supplementary Table 3**). At multivariable analysis ECMO was independently associated with a 5.6-fold increased risk of bleeding, while preoperative SAPS II >70 increased it by 2.9 (**Fig. 2**).

For sensitivity analyses, 21 ECMO patients could be matched to 21 nonECMO patients based on their propensity scores to be ECMO-implanted. Characteristics of matched and

unmatched patients are given in **Supplementary Table 4**. Propensity matching yielded two groups of highly comparable patients in terms of underlying diagnosis, demographic characteristics, type of abdominal procedure and preoperative disease severity (**Tables 1 and 2**). A markedly higher rate of perioperative bleeding was confirmed for ECMO patients compared to matched nonECMO controls, and the notably higher amounts of blood products received by the former.

DISCUSSION

In this study, we assessed the outcomes of patients on ECMO who required emergency abdominal surgery. We found that, although such invasive procedures were feasible, they were associated with a significantly increased risk of bleeding compared to nonECMO ICU patients.

To date, outcomes of abdominal surgery under ECMO have not been reported. Up to 30% of ECMO-treated patients experience bleeding complications, questioning the feasibility of these invasive interventions.(4,6,7) Among 563 ECMO patients who underwent 149 miscellaneous noncardiac surgical procedures, ECMO was associated with a 28% bleeding-complication rate, without bleeding episodes impacting in-ICU mortality. (14) A greater need for blood products was also demonstrated in two populations of patients receiving mechanical circulatory support, including 11 and 14 ECMO-treated patients, who had undergone miscellaneous noncardiac surgical interventions.(15,16). In another study, thoracotomy on ECMO led to unusual and uncontrollable massive hemorrhages.(5) In our cohort, 34% of ECMO-treated patients experienced postoperative bleeding, requiring reintervention in 20% of them and consumption of large amounts of blood products. However, perioperative mortality remained comparable to that of nonECMO patients.

Patients on ECMO frequently develop complex coagulation disorders. Contact with the foreign circuit surfaces activates platelets and the coagulation cascade (12,17–19), responsible

for a hypercoagulation state. In turn, clots forming on the membrane trigger intense fibrinolysis, which, in addition to platelet consumption, is responsible for a secondary hypocoagulation state.(19,20) An acquired von Willebrand syndrome was also described under ECMO.(21) This pathophysiology opens an important area of research to limit the risk of bleeding during invasive procedures in this particular setting.

Intensivists need to evaluate more rigorous anticipation of those coagulation disorders by systematically replacing the ECMO circuit before surgery or providing greater quantities of blood products, particularly fibrinogen and platelets. Antifibrinolytic therapy with tranexamic acid achieved markedly lower bleeding rates in a large, multicenter, randomized trial during coronary-artery surgery under cardiopulmonary bypass, and could also be of interest during abdominal surgery.(22) Finally, better characterization of the patient's coagulation state using thromboelastometry and platelet aggregometry might also help optimize those patients' coagulation states in the future.(23) In our cohort, ECMO patients had lower presurgery platelet counts and fibrinogenemia than nonECMO controls, consistent with more pronounced fibrinolysis. Whether or not a more aggressive protocol could manage coagulation disorders during invasive procedures might be a promising avenue of research.

For surgeons, coagulation disorders considerably modify the benefit/risk ratio of invasive surgery, with important potential implications. Bowel resection of a not viable segment might be prioritized over bowel preservation during ischemia, to avoid, as much as possible, the need for a second-look. Systematic cholecystectomy should be reevaluated in this specific setting and should be avoided if it is not essential. Lastly, noninvasive approaches, like medical treatment of cholecystitis, should be prefered. Taken together, such complex interventions further emphasize the need to manage ECMO-treated patients in centers highly experienced in its medical and surgical aspects.

In our cohort, although ECMO patients' in-ICU mortality was very high, perioperative

mortality and direct surgical complication-triggered mortality remained low and comparable to that of the nonECMO group. It must be kept in mind that our patients predominantly had medical conditions with secondary abdominal complications. Although mortality related reasons can be a matter of debate for this cohort, we think that the underlying disease and extreme severity of ECMO patients accounted, in large part, for the observed mortality. Notably, the cohort contained a high percentage of patients with refractory cardiogenic shock complicated by digestive ischemia, a pathology also associated with high mortality of nonECMO patients.

Finally, our study has several limitations. Although it is the first homogeneous cohort of abdominal surgery procedures under ECMO, the sample size was small. Secondly, our cohort comprised selected medical ICU patients, limiting the external validity of our results. Lastly, our matching procedure used a propensity score to be ECMO-implanted to match ECMO and nonECMO patients. Although this procedure yielded highly comparable groups, in terms of demographics and preoperative characteristics, and the bleeding-event results for the matched cohort were consistent with multivariable analyses of the whole cohort, it cannot be excluded that factors associated with the patients' underlying conditions necessitating ECMO implantation may have accounted for the bleeding rate observed in matched ECMO patients.

We finally observed that the the results of our study, undertaken to assess the outcomes of ECMO-treated patients who required emergency abdominal surgery, revealed that such invasive procedures were feasible, but associated with a markedly increased risk of haemorrhage. Further studies are needed to improve the management of such surgical interventions for patients on ECMO.

Supplemental Digital Content

Supplementary Tables 1–4

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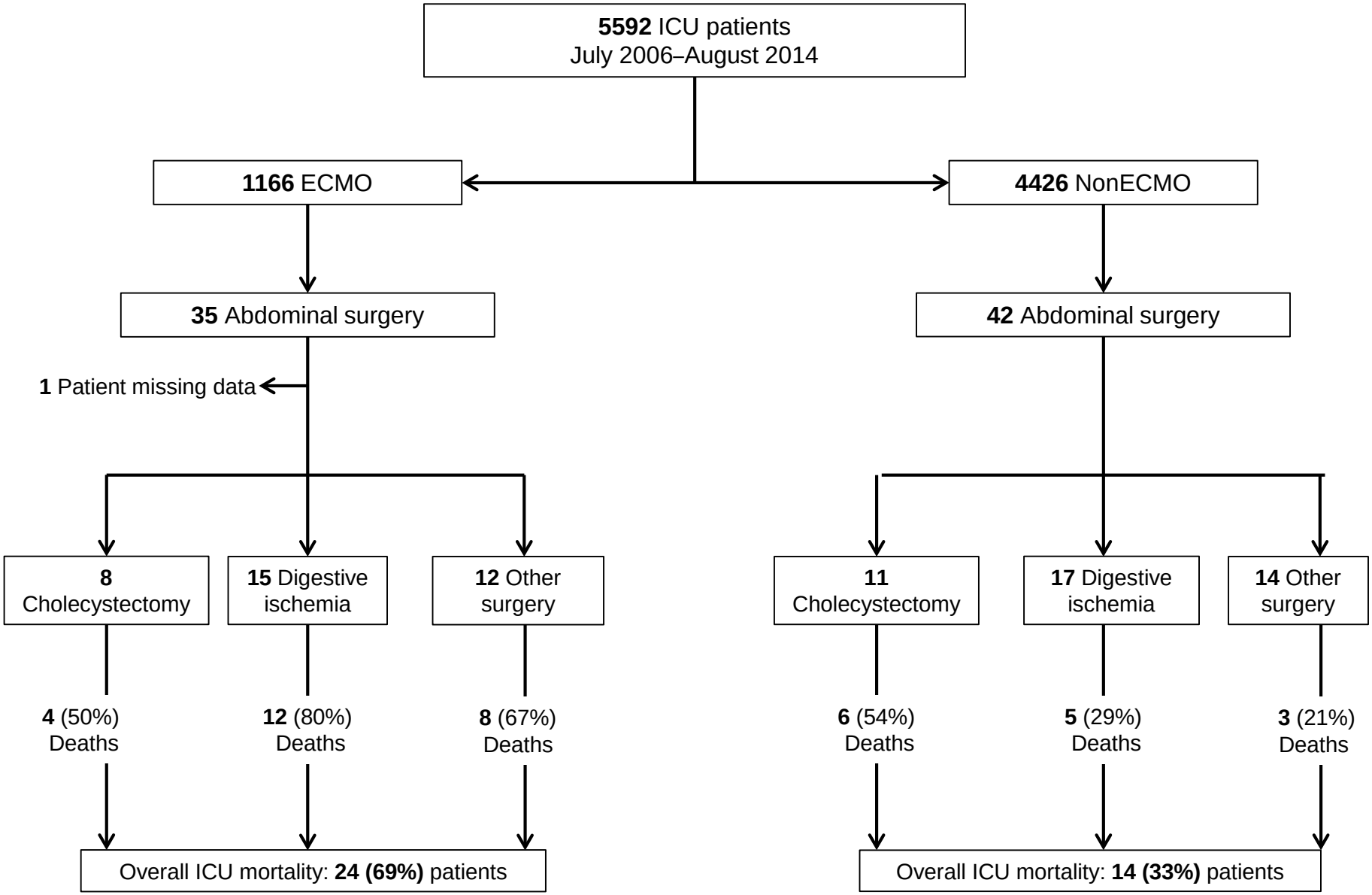
FIGURE LEGENDS

Figure 1. Study flow chart. ICU = intensive care unit; ECMO = extracorporeal membrane oxygenation.

Figure 2. Multivariable analysis results of factors independently associated with perioperative bleeding (≥ 3 packed red blood cell units received during the first 72-hours postoperative). ECMO = extracorporeal membrane; SAPS = Simplified Acute Physiology Score.


5592 ICU patients
July 2006–August 2014
1166 ECMO
4426 NonECMO
35 Abdominal surgery
42 Abdominal surgery
1 Patient missing data
8 Cholecystectomy
15 Digestive ischemia
12 Other surgery
11 Cholecystectomy
17 Digestive ischemia
14 Other surgery
4 (50%) Deaths
12 (80%) Deaths
8 (67%) Deaths
6 (54%) Deaths
5 (29%) Deaths
3 (21%) Deaths
Overall ICU mortality: **24 (69%)** patients
Overall ICU mortality: **14 (33%)** patients

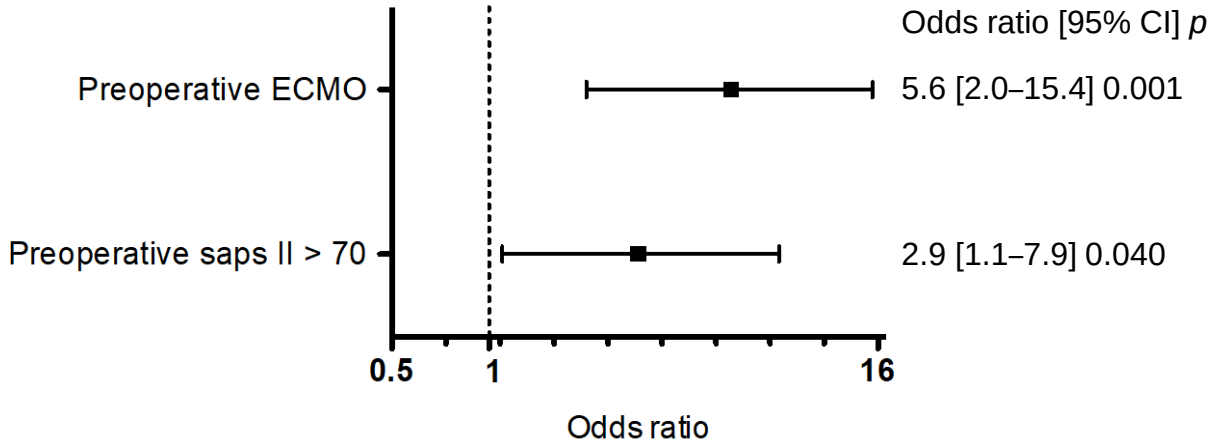

Odds ratio [95% CI] p
Preoperative ECMO
5.6 [2.0–15.4] 0.001
Preoperative saps II > 70
2.9 [1.1–7.9] 0.040
0.5
1
16
Odds ratio

Table 1. Patient Characteristics at ICU Admission

Characteristic	Unmatched Patients (*n* = 77)			Propensity-Matched Patients (n = 42)		
	ECMO (*n* = 35)	nonECMO (*n* = 42)	*p*	ECMO (*n* = 21)	nonECMO (*n* = 21)	*p*
Demographic						
Year	2012 (2011–2013)	2010 (2008–2012)	0.009	2012 (2010–2012)	2010 (2009–2012)	0.14
Age (yr)	59 (43–64)	64 (54–74)	0.02	61 (51–64)	55 (51–63)	0.6
Males	27 (77)	28 (67)	0.45	14 (67)	14 (67)	1.0
Body mass index (kg/m^2)	27 (24–32)	27 (22–29)	0.28	26 (23–31)	26 (23–30)	0.8
Charlson score	2 (1–3)	3 (2–4)	0.09	2 (1–3)	2 (1–4)	0.5
McCabe & Jackson score	2 (1–3)	1.5 (1–2)	0.76	2 (1–3)	1 (1–2)	0.6
Immunocompromised	6 (17)	15 (36)	0.08	5 (24)	6 (29)	1.0
Reason for ICU admission						
Postoperative	19 (54)	19 (45)	0.50	11 (52)	11 (52)	1.0
Sepsis	13 (37)	20 (48)	0.82	9 (43)	8 (38)	1.0
Diagnosis[a]						
Cardiovascular	18 (51)	15 (36)	0.18	11 (52)	12 (57)	1.0
Gastrointestinal	7 (20)	9 (21)	1.00	5 (24)	3 (14)	0.7
Metabolic	0	1 (2)	1.00	0	1 (5)	1.0
Neurologic	0	3 (7)	0.25	0	2 (10)	0.5
Renal or genitourinary	1 (3)	6 (14)	0.12	0	1 (5)	1.0
Respiratory	11 (31)	12 (29)	0.81	5 (24)	5 (24)	1.0
SOFA score	16 (12–17)	11 (7–14)	<0.001	15 (10–17)	14 (10–15)	0.4
SAPS II	71 (60–83)	68 (54–86)	0.76	66 (58–82)	72 (56–88)	0.7
ECMO indication[a]						
Cardiogenic shock	22 (63)	—	—	16 (76)	—	—
Cardiomyopathy	8 (23)	—	—	6 (29)	—	—
Septic shock	5 (14)	—	—	5 (24)	—	—
Myocardial infarction	4 (11)	—	—	2 (10)	—	—
Cardiac arrest	3 (9)	—	—	2 (10)	—	—
Other	2 (6)	—	—	1 (5)	—	—
ARDS	13 (37)	—	—	5 (24)	—	—
ECMO hook-up						

Venoarterial	22 (63)	—	—	16 (76)	—	—
Venovenous	13 (37)	—	—	5 (24)	—	—

Results are expressed as number (%) or median (1^{st}–3^{rd} IQR). Significant differences are in bold type.

SAPS = Simplified Acute Physiology Score; SOFA = Sepsis-related Organ-Failure Assessment; ARDS = acute respiratory distress syndrome; — = not applicable.

[a]several may be involved.

Table 2. Patient's Pre and Intraoperative Characteristics

Characteristic	Unmatched Patients (*n* = 77)			Propensity-Matched Patients (n = 42)		
	ECMO (*n* = 35)	nonECMO (*n* = 42)	*p*	ECMO (*n* = 21)	nonECMO (*n* = 21)	*p*
Preoperative						
ICU admission to surgery interval (d)	7 (2–20)	4 (1–11)	0.02	7 (2–19)	7 (2–14)	0.5
ECMO-to-surgery interval (d)	7 (2–15)	—	—	7 (2–18)	—	—
Temperature (°C)	37.1 (36.3–37.6)	36.8 (36.5–37.7)	0.79	36.9 (36.4–37.7)	37.2 (36.5–37.9)	0.7
Renal replacement therapy	24 (69)	22 (52)	0.17	12 (57)	11 (52)	1.0
Mechanical ventilation	35 (100)	33 (79)	0.003	21 (100)	19 (90)	0.5
Inotrope score (µg/kg/min)[a]	32.5 (6.4–68.3)	21.5 (0.0–85.1)	0.50	26.7 (5.5–59.8)	22.2 (1.2–119.0)	0.9
Curative anticoagulation[b]	12 (34)	18 (43)	0.49	11 (52)	12 (57)	1.0
Bacteriemia	16 (46)	18 (43)	0.82	12 (57)	7 (33)	0.2
Arterial pH	7.38 (7.35–7.43)	7.34 (7.26–7.44)	0.05	7.40 (7.35–7.45)	7.36 (7.28–7.43)	0.3
Blood lactates (mmol/L)	2.9 (1.9–6.3)	2.30 (1.50–7.50)	0.27	3.0 (1.7–6.4)	2.4 (1.4–6.2)	0.6
Bicarbonate (mmol/L)	21 (16–24)	20 (16–23)	0.94	20.4 (16.3–22.8)	20.5 (16.3–22.6)	0.9
Hemoglobin (g/dL)	8.7 (7.8–9.6)	8.8 (8.1–9.5)	0.42	8.9 (8.0–10.0)	8.7 (8.2–9.2)	0.7
Platelet count (G/L)	68 (38–156)	183 (78–265)	<0.001	70 (40–160)	161 (78–277)	0.008
Prothrombin activity (%)	55 (37–66)	63 (41–71)	0.36	55 (38–67)	63 (40–70)	0.5
aPTT ratio	3.8 (2.4–6.6)	1.3 (1.1–1.9)	0.13	1.3 (1.2–1.9)	1.3 (1.1–1.9)	0.5
Fibrinogen (g/L)	3.8 (2.40–6.6)	5.1 (4.2–7.3)	0.04	3.3 (2.2–6.4)	5.1 (4.2–7.3)	0.1
Surgical approach						
Laparotomy	30 (86)	41 (98)	0.08	17 (81)	21 (100)	0.1
Other position	5 (14)	1 (2)	0.09	4 (19)	0	
Type of procedure						
Cholecystectomy	8 (23)	11 (26)	0.80	5 (24)	6 (29)	1.0
Digestive ischemia	15 (43)	17 (40)	1.00	8 (38)	10 (48)	0.8
Other	12 (34)	14 (33)	1.00	8 (38)	5 (24)	0.3
Concomitant procedure						
Stoma	15 (43)	20 (48)	0.82	9 (43)	10 (48)	1.0
Digestive resection	15 (43)	21 (50)	0.65	9 (43)	11 (52)	0.8
Vascular resection	1 (3)	0	0.45	0	0	1.0
Patients transfused	23 (66)	20 (48)	0.17	15 (71)	11 (52)	0.3
PRBCs	2 (0–4)	0 (0–2)	0.008	2 (0–3)	0 (0–2)	0.03

FFP	0 (0–3)	0 (0–2)	0.14	0 (0–3)	0 (0–3)	0.5
Platelets	0 (0–10)	0 (0–0)	**<0.001**	0 (0–9)	0 (0–0)	**0.004**
Bleeding	10 (29)	4 (10)	**0.04**	6 (29)	1 (5)	0.09

Results are expressed as number (%) or median (1^{st}–3^{rd} IQR). Significant differences are in bold type.

aPTT = activated partial thromboplastin time.

[a]Defined as Dobutamine dose + 100 x (Epinephrine dose + Norepinephrine dose), all in μg/kg/min.

[b]Curative anticoagulation was defined as an unfractionated heparin dose >12000 IU per day.

Table 3. Patient's Postoperative Characteristics

Characteristic	Unmatched Patients (*n* = 77)			Propensity-matched patients (*n* = 42)		
	ECMO (*n* = 35)	nonECMO (*n* = 42)	*p*	ECMO (*n* = 21)	nonECMO (*n* = 21)	*p*
Immediate postoperative period (24 h)						
Temperature (°C)	36.4 (34–36.7)	36.4 (35.9–37.0)	0.14	36.2 (33.9–36.7)	36.4 (36.0–37.2)	0.05
Renal replacement therapy	26 (74)	23 (55)	0.09	14 (67)	11 (52)	
Inotrope score (µg/kg/min)	42 (14–87)	25 (10–45)	0.12	42 (10–97)	25 (7–74)	0.6
Arterial pH	7.34 (7.28–7.44)	7.32 (7.25–7.40)	0.31	7.31 (7.26–7.43)	7.30 (7.24–7.39)	0.6
Blood lactates (mmol/L)	4 (2–7)	2.9 (1.9–4.6)	0.19	4.1 (2.0–7.0)	2.8 (1.9–6.3)	0.3
Bicarbonate (mmol/L)	18 (15–22)	18 (17–20)	0.94	17 (14–21)	18 (17–20)	0.4
Hemoglobin (g/dL)	9.5 (7.8–10.1)	10.2 (9.2–11.4)	0.002	9.5 (8.7–10.3)	9.9 (9.2–10.9)	0.4
Prothrombin activity (%)	51 (40–62)	60 (41–70)	0.19	51 (41–60)	60 (38–67)	0.25
aPTT ratio	1.5 (1.2–1.7)	1.3 (1.0–1.8)	0.32	1.4 (1.2–1 .6)	1.3 (1.0–2.0)	0.5
Fibrinogen (g/L)	2.9 (1.9–5.1)	4.8 (3.6–6.6)	0.002	2.7 (2.0–3.6)	4.8 (3.5–6.7)	0.006
Perioperative bleeding (72 h)	26 (74)	14 (33)	<0.001	15 (71)	8 (38)	0.04
Late postoperative period						
Infection	5 (14)	3 (7)	0.46	3 (14)	1 (5)	0.6
Bleeding	12 (34)	1 (2)	<0.001	6 (29)	0	0.02
Operative site	4 (33)	0		3 (14)	0	
Hemoperitoneum	6 (50)	0		2 (10)	0	
Stoma	2 (17)	1 (100)		1 (5)	0	
Reintervention	10 (29)	4 (10)	0.04	5 (24)	1 (5)	0.2
Bleeding	7 (20)	1 (2)	0.02	5 (24)	0	0.04
Infection	3 (9)	3 (7)	1.00	0	1 (5)	1.0
Patients transfused	27 (77)	16 (38)	0.001	20 (95)	17 (81)	0.3
Total PRBCs	13 (6–22)	3 (0–5)	<0.001	12 (5–14)	4 (1–14)	0.04
Total FFP	9 (3–17)	0 (0–4)	<0.001	9 (3–16)	0 (0–10)	0.005
Total platelets	12 (3–22)	0 (0–8)	<0.001	16 (4–23)	0 (0–10)	0.02
Mechanical ventilation duration (d)	20 (10–29)	12 (4–23)	0.03	15 (10–26)	18 (6–28)	0.9
RRT duration (d)	7 (2–18)	4 (1–10)	0.06	7 (2–11)	4 (2–14)	0.9
In-ICU death	24 (69)	14 (33)	0.003	16 (76)	9 (43)	0.06
Perioperative mortality (<72 h)	4 (11)	5 (12)	1.0	0	2 (10)	0.5

ICU stay (d)	28 (11–46)	23 (14–48)	0.61	17 (11–36)	33 (15–60)	0.1

Results are expressed as number (%) or median (1^{st}–3^{rd} IQR). Significant differences are in bold type.

aPTT = activated partial thromboplastin time; FFP = fresh frozen plasma units; PRBCs = packed red blood cell units; RRT = renal replacement therapy.

Supplemental Digital Content

emergency abdominal surgery Outcomes of critically ill patients on extracorporeal membrane oxygenation

Supplementary Table 1. Other Surgical Procedures

		ECMO (*n* = 35)		nonECMO (*n* = 42)	
		Unmatched	Matched	Unmatched	Matched
Disease	Surgical procedure	(*n* = 14)	(*n* = 21)	(*n* = 21)	(*n* = 21)
Post C-section peritonitis	Intestinal resection with stoma		1		
Intestinal perforation of digestive lymphoma	Intestinal resection with stoma			1	
Obstruction by sigmoid cancer	Stoma			1	
Evisceration after Lewis–Santy intervention	Drain in hematoma		1		
Appendicitis with peritonitis	Appendectomy		1		
Anastomotic leakage with intestinal perforation	Drain with jejunostomy	1			
Hemoperitoneum	Liver packing with splenectomy	1			
Postcolonoscopy pneumoperitoneum	Laparoscopy with drain	1			
Perineum cellulitis	Débridement + stoma		2		
Perineum cellulitis	Débridement		2		
Colectasia	Stoma + cholecystectomy		1		
Esophageal perforation	Suture + mediastinal and left thoracic drainage			1	
Colorectal anastomosis leakage	Hartmann's intervention			2	
Left strangulated inguinal hernia	Hartmann's intervention			1	
Intestinal obstruction	Intestinal resection with stoma			1	
Esophagus perforation	Total gastrectomy, jejunostomy & cholecystectomy				1
Intestinal obstruction	Adhesion resection				2
Duodenal ulcer perforation	Duodenal suture				1
Malaria splenic rupture	Splenectomy				1
Undetermined septic shock	Explorative laparotomy	1		2	

ECMO = extracorporeal membrane oxygenation.

Supplementary Table 2. Comparison of Bleeding Events and Outcomes between Venoarterial (VA)- and Venovenous (VV)-Extracorporeal Membrane Oxygenation (ECMO)

Characteristic	VV-ECMO (*n* = 13)	VA-ECMO (*n* = 22)	*p*
Intraoperative			
Patients transfused	9 (69)	14 (64)	1
Complication	6 (46)	4 (18)	0.12
Overt bleeding	6 (46)	4 (18)	0.05
Postoperative			
Complication	8 (62)	11 (50)	0.7
Bleeding	6 (46)	7 (32)	0.48
Reintervention	4 (31)	7 (32)	1
Reintervention for bleeding	2 (15)	5 (23)	0.69
Patients transfused	9 (69)	18 (82)	1
Outcome			
ECMO duration (d)	7 (5-21)	10 (7-26)	0.33
Explantation	5 (38)	10 (45)	0.74
Death	8 (62)	16 (73)	0.71
Hospitalization stay (d)	20 (4–32)	12 (5–18)	0.52

Results are expressed as number (%) or median (1^{st}–3^{rd} IQR).

Supplementary Table 3. Univariable Analyses of Risk Factors for Perioperative Bleeding[a]

Characteristic	No bleeding (*n* = 37)	Bleeding (*n* = 40)	*p*
Demographic			
Year	2011 (2009–2013)	2012 (2009–2012)	0.55
Age (yr)	64 (56–74)	58 (44–65)	0.006
Men	25 (68)	30 (75)	0.61
Body mass index (kg/cm^2)	26 (20–29)	28 (25–32)	0.02
Charlson score	3 (1–4)	2 (1–3)	0.14
McCabe & Jackson score	1 (1–2)	2 (1–3)	0.18
Immunocompromised	10 (27)	11 (28)	1.0
Reason for ICU admission			
Postoperative cardiac surgery	15 (41)	23 (58)	0.17
Sepsis	18 (49)	15 (38)	0.36
Organ failure			
Cardiovascular	17 (46)	16 (40)	0.65
Gastrointestinal	5 (14)	11 (28)	0.17
Metabolic	0	1 (3)	1.0
Neurologic	2 (5)	1 (3)	0.61
Renal or genitourinary	4 (11)	3 (8)	0.70
Respiratory	9 (24)	14 (35)	0.32
Preoperative			
ICU-to-surgery interval (d)	6 (2–12)	7 (2–14)	0.35
SOFA score	12 (8–17)	15 (13–18)	0.02
SAPS II	70 (49–84)	77 (70–84)	0.06
ECMO	9 (24)	25 (63)	0.001
Mechanical assistance			
Venoarterial	6 (16)	15 (38)	0.04
Venovenous	3 (8)	10 (25)	0.07
Temperature (°C)	36.8 (36.2–37.6)	37.2 (36.6–37.8)	0.11
Renal replacement therapy	16 (43)	30 (75)	0.006
Mechanical ventilation	29 (78)	39 (98)	0.01
Inotrope score (μg/kg/min)[b]	27 (0–87)	25 (6–64)	0.87

Curative anticoagulation	14 (38)	16 (40)	0.81
Bacteriemia	12 (32)	22 (55)	0.06
Arterial pH	7.35 (7.29–7.45)	7.38 (7.33–7.43)	0.88
Blood lactates (mmol/L	2.7 (1.6–6.5)	2.4 (1.7–6.1)	0.77
Bicarbonate (mmol/L)	19 (16–23)	21 (17–24)	0.27
Hemoglobin (g/dL)	8.7 (8.0–9.6)	8.8 (7.9–9.6)	0.90
Platelet count (G/L)	156 (69–270)	78 (45–193)	0.06
Prothrombin activity (%)	63 (37–72)	58 (39–67)	0.52
aPTT ratio	1.3 (1.1–1.9)	1.5 (1.2–2.0)	0.45
Fibrinogen (g/L)	4.6 (3.6–7.3)	5.2 (2.9–6.7)	0.71
Intraoperative			
Type of surgery			
Cholecystectomy	8 (22)	11 (28)	0.60
Ischemia	18 (49)	14 (35)	0.25
Other	11 (30)	15 (38)	0.63
Laparotomy	37 (100)	34 (85)	**0.03**
Stoma	16 (43)	19 (48)	0.81
Digestive resection	18 (49)	18 (45)	0.82

Results are expressed as number (%) or median (1^{st}–3^{rd} IQR). Significant differences are in bold type.

[a] Defined as having received ≥3 PRBC units within the first 72-h postoperative.

[b]Defined as Dobutamine dose + 100 x (Epinephrine dose + Norepinephrine dose), all in μg/kg/min.

aPTT = activated partial thromboplastin time; SAPS = simplified Acute physiology score; SOFA = Sepsis-related Organ Failure Assessment Score.

Supplementary Table 4. Comparison of Matched vs Unmatched Patients, According to their Propensity Score To Be ECMO-Implanted

	ECMO (*n* = 35)		nonECMO (n = 42)	
	Unmatched	Matched	Matched	Unmatched
Characteristic	(*n* = 14)	(*n* = 21)	(n = 21)	(*n* = 21)
Demographic				
Year	2012 (2011–2014)	2012 (2010–2012)	2010 (2009–2012)	2010 (2008–2013)
Age (yr)	55 (34–64)	61 (51–64)	55 (51–63)	70 (64–77)[b]
Male	13 (93)	14 (67)	14 (67)	14 (67)
Body mass index (kg/m^2)	29 (26–37)	26 (23–31)	26 (23–30)	28 (19–29)
Charlson score	2 (0–3)	2 (1–3)	2 (1–4)	3 (2–4)
McCabe & Jackson score	1 (0–3)	2 (1–3)	1 (1–2)	2 (1–2)
Immunocompromised	1 (7)	5 (24)	6 (29)	9 (43)
Reason for ICU admission				
Postoperative	8 (57)	11 (52)	11 (52)	8 (38)
Sepsis	4 (29)	9 (43)	8 (38)	12 (57)
Organ failure				
Cardiovascular	7 (50)	11 (52)	12 (57)	3 (14)[b]
Gastrointestinal	2 (14)	5 (24)	3 (14)	6 (29)
Metabolic	0	0	1 (5)	0
Neurologic	0	0	2 (10)	1 (5)
Renal or genitourinary	1 (7)	0	1 (5)	5 (24)
Respiratory	6 (43)	5 (24)	5 (24)	7 (33)
SOFA score	17 (13–18)	15 (10–17)	14 (10–15)	7 (4.5–13.5)[b]
SAPS II score	74 (70–84)	66 (58–82)	72 (56–88)	66 (45–84)
ECMO indication				
Cardiogenic shock	6 (43)	16 (76)	—	—
Cardiomyopathy	2 (14)	6 (29)	—	—
Septic shock	0	5 (24)	—	—
Myocardial infarction	2 (14)	2 (10)	—	—
Cardiac arrest	1 (7)	2 (10)	—	—
Other	1 (7)	1 (5)	—	—
ARDS	8 (57)	5 (24)	—	—

ECMO				
Venoarterial	6 (43)	16 (76)	—	—
Venovenous	8 (57)	5 (24)	—	—
Preoperative				
ICU admission-to-surgery interval (d)	9 (2–22)	7 (2–19)	7 (2–14)	2 (1–10)[a]
ECMO-to-surgery interval (d)	6 (2–12)	7 (2–18)	—	—
Temperature (°C)	37.2 (35.7–37.8)	36.9 (36.4–37.7)	37.2 (36.5–37.9)	36.6 (36.3–37.6)
Renal replacement therapy	12 (86)	12 (57)	11 (52)	11 (52)
Mechanical ventilation	14 (100)	21 (100)	19 (90)	14 (67)
Inotrope score (μg/kg/min)[a]	33.2 (3.8–96.6)	26.7 (5.5–59.8)	22.2 (1.2–119.0)	20.8 (0–73.9)
Curative anticoagulation	1 (7)[b]	11 (52)	12 (57)	6 (28)
Bacteremia	4 (29)	12 (57)	7 (33)	11 (52)
Arterial pH	7.38 (7.35–7.42)	7.40 (7.35–7.45)	7.36 (7.28–7.43)	7.29 (7.25–7.44)
Blood lactates (mmol/L)	2.8 (1.8–6.4)	3.0 (1.7–6.4)	2.4 (1.4–6.2)	2.2 (1.7–5.5)
Bicarbonate (mmol/L)	20.8 (15.6–24.2)	20.4 (16.3–22.8)	20.5 (16.3–22.6)	20.2 (15.4–24.7)
Hemoglobin (g/dL)	8.0 (7.5–8.9)	8.9 (8.0–10.0)	8.7 (8.2–9.2)	9.0 (8.0–9.8)
Platelet count (G/L)	57 (36–112)	70 (40–160)	161 (78–277)	193 (69–248)
Prothrombin activity (%)	55 (36–69)	55 (38–67)	63 (40–70)	63 (43–72)
aPTT ratio	1.7 (1.4–1.9)	1.3 (1.2–1.9)	1.3 (1.1–1.9)	1.3 (1.1–1.8)
Fibrinogen (g/L)	5.0 (2.5–7.0)	3.3 (2.2–6.4)	5.1 (4.2–7.3)	5.2 (3.9–7.4)

Values are median (1st–3rd IQR) or *n* (%).

[a]Defined as Dobutamine dose + 100 x (Epinephrine dose + Norepinephrine dose), all in μg/kg/min.

aPTT = activated partial thromboplastin time; SAPS = simplified Acute physiology score; SOFA = Sepsis-related Organ Failure Assessment Score; ARDS = acute respiratory distress syndrome; — = not applicable.

Within group unmatched-vs.-matched comparisons: [a]$p < 0.05$, [b]$p < 0.01$.