



Traumatic brain injury in children with thoracic injury: clinical significance and impact on ventilatory management

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Abstract

Purpose This study aims to describe the epidemiology and management of chest trauma in our center, and to compare patterns of mechanical ventilation in patients with or without associated moderate-to-severe traumatic brain injury (TBI).

Methods All children admitted to our level-1 trauma center from February 2012 to December 2018 following chest trauma were included in this retrospective study.

Results A total of 75 patients with a median age of 11 [6–13] years, with thoracic injuries were included. Most patients also had extra-thoracic injuries ($n = 71$, 95%) and 59 (79%) had TBI. A total of 52 patients (69%) were admitted to intensive care and 31 (41%) were mechanically ventilated. In patients requiring mechanical ventilation, there was no difference in tidal volume or positive end-expiratory pressure in patients with moderate-to-severe TBI when compared with those with no-or-mild TBI. Only one patient developed Acute Respiratory Distress Syndrome. A total of 6 patients (8%) died and all had moderate-to-severe TBI.

Conclusion In this small retrospective series, most patients requiring mechanical ventilation following chest trauma had associated moderate-to-severe TBI. Mechanical ventilation to manage TBI does not seem to be associated with more acute respiratory distress syndrome occurrence.

Keywords Chest trauma · Mechanical ventilation · Pulmonary contusion · Traumatic brain injury · Children

Introduction

Trauma remains a leading cause of childhood mortality worldwide. The World Health Organization estimates that 950,000 children under the age of 18 died as a result of an injury in 2004 [1]. Between 4 and 8% of all pediatric trauma victims present with thoracic injury, which although infrequent is associated with higher mortality [2–4]. These patients often present with associated traumatic brain injury (TBI), and the most commonly identified thoracic injury is pulmonary contusion [2]. Acute Respiratory Distress

Syndrome (ARDS) develops in a minority of children following trauma but is associated with worse outcomes [5–8]. Clinicians are then faced with potentially opposing paradigms regarding the management of mechanical ventilation in such patients; while tolerating moderate hypercapnia and hypoxemia may limit ventilator-induced lung injury [9], they are well-known factors worsening outcome in patients with severe TBI [10]. Finally, although the management of chest trauma patients is well defined in adults [11], pediatric-specific guidelines are lacking and current strategies for the management of chest trauma in children are mostly based upon adult protocols.

In the present study, we hypothesize that the presence of a moderate-to-severe TBI associated with chest trauma leads to differences in the management of mechanical ventilation. In this context, the aim of this study is to describe a single-center cohort of chest trauma in the pediatric population and to compare patterns of mechanical ventilation in patients with or without associated moderate-to-severe TBI.

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Materials and methods

Study design and patients

This monocentric retrospective study was conducted in the pediatric trauma room of the Grenoble-Alps University Hospital, the only level-1 pediatric trauma center in the French Alps. All patients up to 16 years of age included in the TRENAU (The Northern French Alps Trauma System) registry and admitted to the trauma room from February 2012 to December 2018 were eligible. Patients were included if they presented with chest trauma, as reported by the on-site physician or by the trauma leader in the first admission report, based on clinical examination and/or chest imagery. The TRENAU registry collects medical data from the trauma scene to the admission in the PICU/ICU and was approved by the regional institutional review board (*Comité d’Ethique des Centres d’Investigation Clinique de l’inter-région Rhône-Alpes-Auvergne*, IRB number 5708). This manuscript adheres to the applicable STROBE guidelines [12].

Collected data

All data were collected from electronic medical records (Clinisoft, General Electrics). Demographic data included age and gender while clinical data included mechanism of injury, severity scores [Injury Severity Scores (ISS), Abbreviated Injury Score (AIS), Pediatric Trauma Score (PTS), Pediatric Risk of Mortality (PRISM)] [13–15], initial clinical assessment, radiological and laboratory findings, and management. Regarding the initial clinical assessment, respiratory failure was defined as pulse oximetry < 90% in room air at the scene, hemodynamic failure was defined as the need for > 40 mL/kg of fluid or continuous infusion of vasopressors within the first 4 h after ICU admission, and moderate-to-severe TBI was defined by a Glasgow Coma Scale (GCS) < 13 at ICU admission. We defined myocardial injury as a troponin level > 50 ng/L and/or a cardiac dysfunction on cardiac ultrasound at admission. Therapies recorded included blood product transfusion, non-orthopedic surgical intervention, invasive ventilation for more than 1 day, and the use of vasopressors, neuromuscular blockers or antibiotics within the first 24 h.

The type and mode of mechanical ventilation were collected at admission, on days 2 and 3, as well as the following parameters: set FiO_2 , positive end-expiratory pressure (PEEP), tidal volume (V_T), and pressure support level. For set parameters, mean and maximum were collected, and maximum during stay was considered as the maximum

value set for at least one hour). The occurrence of ARDS (commonly diagnosed according to PALICC definition [9]) and pneumonia (diagnosed in the context of fever, purulent tracheobronchial secretions, new or changing infiltrates on the chest radiography occurring > 48 h after admission, and confirmation by positive cultures) was assessed retrospectively based on the final medical report. Pneumonia onset was considered early when occurring between days 1 and 4 or late when occurring from day 4. Contusion was defined as any damage to the parenchyma. Finally, adherence with lung-protective ventilation strategy was assessed retrospectively and defined as within targets when V_T was between 6 and 8 ml/kg.

Recorded outcomes included ICU and hospital length of stay, duration of mechanical ventilation, Pediatric Overall Performance Category (POPC) score [16] at hospital discharge and in-hospital mortality.

In our center, we do not have any written protocol for ventilatory management of patients with chest trauma and it was based on the clinical judgement of the team in charge. Since the national recommendations on this topic were conducted by a local colleague (PB), we assume that they are well known to local physicians in charge of pediatric patients with severe trauma. Patients are usually intubated in case of 1/neurological failure with Glasgow Coma Score < 8, 2/severe hemodynamic failure not improved by initial management, and 3/respiratory failure with SpO_2 < 92% despite appropriate management, including low-flow oxygen therapy. A cardiac ultrasound is performed at admission, as well as a complete biological testing including Troponin.

Statistical analysis

Descriptive statistical analyses were performed using SPSS (SPSS 26.0, Chicago, IL, USA). Tests were bilateral, and a p value < 0.05 was considered as statistically significant. Categorical variables were expressed as number (%) and compared using chi-square test (χ^2) or Fisher’s exact test (when expected frequencies were less than five), as appropriate. The distribution of continuous variables was studied by frequency histogram and QQ plot, complemented by Shapiro–Wilk test if necessary. Continuous variables were expressed as mean (standard deviation, SD) or median [interquartile range, IQR] and compared using the unpaired Student’s t test or the non-parametric Mann–Whitney U test, as appropriate.

Results

Study population

During the study period, 657 patients younger than 16 years of age were admitted to our level-1 trauma center ICU and

recorded in the TRENAU registry. Of them, 75 (11.4%) presented with chest trauma and were included in our analysis (Fig. 1). Baseline characteristics of participants are presented in Table 1. Their median age was 11 years [6–13] and 50 (67%) were male. Falls were the main mechanism for trauma ($n = 45$, 60%). Pulmonary contusion ($n = 64$, 85%) pneumothorax ($n = 37$, 49%) and rib fracture ($n = 14$, 19%) were the most commonly identified thoracic injuries. Most patients also had associated extra-thoracic injuries ($n = 71$, 95%), mainly TBI ($n = 59$). At admission in the trauma room, 26 (35%) of patients had a respiratory or hemodynamic failure. Fifty-two patients (69%) were transferred to ICU and 31 (41%) were mechanically ventilated.

As shown in Table 1, patients with a moderate-to-severe TBI had similar baseline demographic characteristics to those with no-or-mild TBI. More patients in the moderate-to-severe TBI group received blood products in the first 24 h (48 vs. 5%, $p < 0.001$) and inotropic/vasopressors during their stay (85 vs. 7%, $p < 0.001$) (Table 2).

Ventilatory management

A majority of patients with moderate-to-severe TBI required invasive mechanical ventilation ($n = 26$, 79%), compared to only five patients (12%) in the no-or-mild TBI group ($p < 0.001$). A total of four patients received non-invasive ventilation during their stay, three of which subsequently required invasive mechanical ventilation as well. Eleven (15%) patients had a chest tube inserted. Overall, only one patient developed an ARDS during his stay and he did not present with TBI. As shown in Table 3, most mechanically ventilated patients were supported by volume-assisted ventilation during their ICU stay ($n = 23$, 82%). The median V_T on day 1 was 7 [7, 8] mL/kg with similar values on days 2 and 3 (Fig. 2). On day 1, 5 (21%) and 3 (13%) patients had a median V_T higher than 8 and 10 mL/kg, respectively. All these patients were in the moderate-to-severe TBI group. The median set PEEP was 5 [4, 5] cmH₂O without any

significant difference between days 1, 2 and 3. On day 1, 2 and 3, median FiO₂ was 40% [35–49], 30% [30–40] and 30% [30–40], respectively.

Outcomes

Over the study period, 6 patients (8%) died, and all had moderate-to-severe TBI (Table 2). Twelve (16%) and 6 (8%) patients developed early- and late-onset pneumonia during their ICU stay, respectively. The incidence of early-onset (29 vs. 7%, $p = 0.03$) and late-onset pneumonia (18 vs. 0%, $p < 0.01$) was significantly higher in the moderate-to-severe TBI group. Patients with moderate-to-severe TBI had longer ICU (0 [0–2] vs. 5 [2–15] days, $p < 0.001$) and hospital length of stay (7 [5–8] vs. 9 [4–32] days, $p = 0.02$).

Discussion

In this retrospective study on children admitted to our level-1 pediatric trauma center with chest trauma, only a minority required invasive mechanical ventilation, and most of the patients who did presented associated moderate-to-severe TBI.

This is the first study comparing mechanical ventilation strategies in children with chest trauma according to the presence and severity of an associated TBI. Since there is a lack of guidelines regarding the ventilatory management of chest trauma in children, ventilatory parameters are usually set to limit the risk of ventilator-induced lung injury based on adult recommendations [11]. ARDS is a rare complication of chest trauma [8], but early lung-protective ventilation may limit its occurrence [7]. However, the high incidence of associated TBI in this population reported in the literature [7, 17] as well as in the present study, may deter clinicians from applying lung-protective ventilation in favor of preventing secondary neurological insults. In an observational study in adults, Pelosi et al. [18] found that

Fig. 1 Flowchart of the study

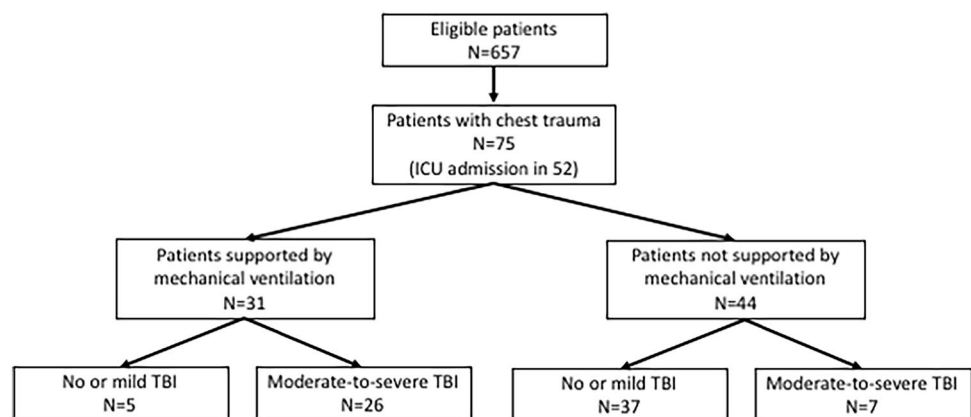


Table 1 Clinical characteristics of patients according to the presence and severity of traumatic brain injury

	<i>n</i>	Total, <i>n</i> =75	<i>n</i>	No-or-mild TBI, <i>n</i> =42	<i>n</i>	Moderate-to-severe TBI, <i>n</i> =33	<i>p</i> value
Age (years), median [IQR]	75	11 [6–13]	42	11 [7–13]	33	10 [6–13]	0.73
Males, <i>n</i> (%)	75	50 (67)	42	30 (71)	33	20 (61)	0.34
Mechanism of injury							
Context							
Fall, <i>n</i> (%)	75	45 (60)	42	26 (62)	33	19 (58)	0.81
Motor vehicle, <i>n</i> (%)	75	25 (33)	42	13 (31)	33	12 (36)	0.63
Domestic, <i>n</i> (%)	75	2 (3)	42	1 (2)	33	1 (3)	1
Other, <i>n</i> (%)	75	4 (5)	42	2 (5)	33	2 (6)	1
Penetrating trauma, <i>n</i> (%)	75	3 (4)	42	2 (5)	33	1 (3)	1
Mountain accident, <i>n</i> (%)	75	31 (41)	42	18 (43)	33	13 (39)	0.81
Thoracic injuries							
Pulmonary contusion, unilateral, <i>n</i> (%)	64	41 (64)	34	25 (74)	30	16 (53)	0.12
Pulmonary contusion, bilateral, <i>n</i> (%)	64	22 (34)	34	8 (24)	30	14 (47)	0.07
Rib fractures, <i>n</i> (%)	75	14 (19)	42	10 (24)	33	4 (12)	0.24
Pneumothorax, <i>n</i> (%)	75	37 (49)	42	25 (60)	33	12 (29)	0.06
Hemothorax, <i>n</i> (%)	75	8 (11)	42	3 (7)	33	5 (15)	0.29
Myocardia contusion, <i>n</i> (%)	75	9 (12)	42	1 (2)	33	8 (19)	<0.01
Mediastinal lesions, <i>n</i> (%)	75	3 (4)	42	2 (5)	33	1 (3)	1
Other pulmonary lesions, <i>n</i> (%)	75	22 (29)	42	12 (29)	33	10 (30)	1
Extra-thoracic injuries	75	71 (95)	42	39 (93)	33	33 (100)	0.25
TBI, <i>n</i> (%)	75	59 (79)	42	27 (64)	33	33 (100)	<0.001
Facial trauma, <i>n</i> (%)	75	21 (28)	42	9 (21)	33	12 (36)	0.20
Spinal trauma, <i>n</i> (%)	75	21 (28)	42	12 (29)	33	9 (27)	1
Abdominal trauma, <i>n</i> (%)	75	24 (32)	42	13 (30)	33	12 (36)	0.63
Orthopedic trauma, <i>n</i> (%)	75	30 (40)	42	15 (36)	33	15 (45)	0.48
Clinical data at trauma room admission							
SpO ₂ , median [IQR]	74	100 [99–100]	42	100 [99–100]	32	100 [100–100]	0.38
Respiratory rate, breath/min, median [IQR]	72	23 [20–26]	40	24 [20–29]	32	22 [20–25]	0.06
Temperature, °C, median [IQR]	70	36.9 [36.0–37.3]	39	37.0 [36.7–37.6]	31	36.0 [34.8–36.9]	<0.001*
Mean blood pressure, mmHg, median [IQR]	66	77 [70–87]	38	74 [70–86]	28	78 [70–89]	0.62
Hemodynamic failure, <i>n</i> (%)	74	24 (32)	32	21 (66)	42	3 (7)	<0.001*
Glasgow Coma Score before intubation, median [IQR]	72	13 [7–15]	40	15 [14,15]	32	7 [3–9]	<0.001*
PTS at admission, median [IQR]	69	6 [4–9]	40	8 [7–10]	29	4 [1–5]	<0.001*
Thoracic AIS score, median [IQR]	75	3 [3, 4]	42	3 [3, 4]	33	3 [3,4]	0.11
ISS at admission, median [IQR]	75	25 [17–34]	42	22 [13–25]	33	34 [25–41]	<0.001*
PRISM Score at admission, median [IQR]	74	5 [1–8]	41	1 [0–4]	33	8 [6–15]	<0.001*
Laboratory data at admission							
Hemoglobin (g/dL), median [IQR]	73	124 [110–135]	40	125 [115–135]	33	118 [106–134]	0.10
PvCO ₂ (mmHg), median [IQR]	68	41 [37–47]	33	38 [36–42]	33	43 [38–52]	0.02*
pH, median [IQR]	53	7.4 [7.3–7.4]	21	7.39 [7.37–7.41]	32	7.32 [7.20–7.39]	<0.01*
Glucose level (g/L), median [IQR]	72	7.1 [5.8–10.5]	40	7.1 [5.7–8.9]	32	7.2 [5.8–12.5]	0.04*

Values are presented in number (%) or median [interquartile range, IQR]

AIS Abbreviated Injury Scale severity ***score, ISS Injury Severity Score, PaO₂ arterial partial pressure of oxygen, PRISM pediatric risk of mortality, PTS Pediatric Trauma Score, PvCO₂ venous partial pressure of carbon dioxide, SpO₂ oxygen saturation, TBI traumatic brain injury

**p* value <0.05

Table 2 ICU management and outcomes of patients according to the presence and severity of traumatic brain injury

	<i>n</i>	Total, <i>n</i> = 75	<i>n</i>	No-or-mild TBI, <i>n</i> = 42	<i>n</i>	Moderate-to-severe TBI, <i>n</i> = 33	<i>p</i> value
ICU management							
Inotrope/vasopressor during stay, <i>n</i> (%)	52	32 (62)	21	4 (17)	31	28 (90)	<0.001*
Blood products in the first 24 h, <i>n</i> (%)	52	18 (35)	21	2 (10)	31	16 (52)	<0.001*
Antibiotics during stay, <i>n</i> (%)	52	44 (85)	21	16 (76)	31	28 (90)	<0.001*
Tracheotomy, <i>n</i> (%)	52	2 (4)	21	0 (0)	31	2 (6)	0.19
Chest tube during stay, <i>n</i> (%)	52	11 (22)	21	4 (19)	31	7 (22)	0.19
Noninvasive ventilation during stay, <i>n</i> (%)	52	4 (8)	21	1 (5)	31	3 (10)	0.30
Duration of noninvasive ventilation, days, median [IQR]	4	3 [1–9]	1	1 [1–1]	3	5 [3–13]	0.42
Invasive mechanical ventilation during stay, <i>n</i> (%)	52	31 (60)	21	5 (24)	31	26 (84)	<0.001*
Duration of invasive mechanical ventilation, days, median [IQR]	31	5 [1–11]	5	5 [1–6]	26	5 [1–18]	0.20*
Outcome							
ARDS during stay, <i>n</i> (%)	75	1 (1)	42	1 (2)	33	0 (0)	1
ICU length of stay, median [IQR]	75	-	42	0 [0–2]	33	5 [2–15]	<0.001*
Hospital length of stay, median [IQR]	68	7 [5–11]	40	7 [5–8]	28	9 [4–32]	0.02*
Early-onset pneumonia, <i>n</i> (%)	75	12 (16)	42	3 (7)	33	9 (27)	0.03*
Late-onset pneumonia, <i>n</i> (%)	75	6 (8)	42	0 (0)	33	6 (18)	<0.01*
POPC score at ICU discharge, median [IQR]	75	-	42	1 [1, 2]	33	3 [2–4]	<0.001*
Death, <i>n</i> (%)	75	6 (8)	42	0 (0)	33	6 (18)	0.01*

Values are presented in number (%) or median [interquartile range, IQR]

ARDS acute respiratory distress syndrome, ICU intensive care unit; POPC pediatric overall performance category, TBI traumatic brain injury

**p* value < 0.05

brain injury patients were delivered higher tidal volume and lower PEEP levels than those ventilated for non-neurologic reasons. There is limited evidence that the occurrence of pulmonary contusion and hypoxemia in children with severe head injury is associated with a worst outcome [19]. In the present study, we found that ventilation parameters were similar whether moderate-to-severe TBI was present or not, and overall adhered to lung-protective mechanical ventilation principles. The incidence of ARDS was very low in our cohort, and that could be explained by two reasons. First, the retrospective design did not allow us to precisely assess the Berlin criteria a posteriori while ARDS is probably underestimated and underreported [6]. Second, as assessed by the trauma severity scores we used, patients included in our cohort are overall less severe than patients reported in other observational studies [17, 20]. We also found that there were fewer penetrating injuries than in the North American studies, although they are generally associated with poorer outcomes [21].

The epidemiology of chest trauma in our cohort differed slightly from previously published reports [22, 23] with a higher proportion of trauma due to falls as compared to motor vehicle accidents. This could be explained by the location of our trauma center in the French Alps, an area where mountain sports are commonly practiced [24, 25].

With regard to thoracic injuries in children, we confirmed published data showing that pulmonary contusion is most frequent, while rib fractures are scarce.

Limitations

This study presents several limitations. First, the retrospective design limits the amount and quality of collected data, especially regarding ventilation. For example, driving pressure or oxygen saturation index was not available and some data were available only at admission and not at D2/D3. Also, the number of mechanically ventilated patients in the no-or-mild TBI group is very limited, hinting at the fact that neurological status strongly impacts the decision to initiate mechanical ventilation. It was impossible to properly determine the indication for intubation retrospectively. Data such as PaO₂ or oxygen saturation index would have been relevant to precisely assess oxygenation. Finally, this is single-center study with a small sample, making our findings difficult to generalize. We included patients with a wide range of chest lesions which constitutes a heterogenous population, making analysis more hazardous. We found that the etiology of thoracic trauma in our center was different from other locations and that makes generalizability to other populations

Table 3 Ventilatory settings and patterns according to the presence and severity of traumatic brain injury

		No-or-mild TBI, <i>n</i> = 5		Moderate-to-severe TBI, <i>n</i> = 26		<i>p</i> value
		<i>n</i>		<i>n</i>		
Initial ventilation mode, <i>n</i> (%)	Volume-assisted ventilation	4	4 (100)	24	17 (71)	0.55
	Other	4	0 (0)	24	7 (29)	
Main ventilation mode during stay, <i>n</i> (%)	Volume-assisted ventilation	4	4 (100)	24	19 (79)	1
	Other	4	0 (0)	24	5 (21)	
Tidal volume (mL/kg), median [IQR]	Day 1	3	7 [7, 8]	21	7 [7, 8]	0.86
	Day 2	0	–	13	7 [6–8]	–
	Day 3	0	–	12	6 [6, 7]	–
	Maximum during stay	3	7 [7, 8]	21	9 [8–10]	<0.01*
PEEP (cmH ₂ O), median [IQR]	Day 1	4	4 [2–4]	25	5 [4, 5]	0.17
	Day 2	1	4 (–)	14	5 [4, 5]	–
	Day 3	1	4 (–)	13	4 [4, 5]	–
	Maximum during stay	4	4 [3, 4]	25	5 [5, 5]	0.22
PvCO ₂ (kPa), median [IQR]	Day 1	5	5.0 [4.3–6.1]	26	5.3 [4.7–6.1]	0.44
	Day 2	5	5.7 [4.9–5.8]	26	5.0 [4.6–5.5]	0.41
	Day 3	5	5.7 [5.4–6.1]	23	5.2 [4.8–5.9]	0.21
FiO ₂ , median [IQR]	Day 1	4	38 [34–43]	24	40 [35–49]	0.37
	Day 2	1	35	14	30 [30–41]	–
	Day 3	1	35	12	30 [30–35]	–
	Maximum during stay	4	43 [34–50]	25	45 [40–60]	0.43
Measured respiratory rate (breath/min), median [IQR]	Day 1	3	20 [18–23]	24	24 [21–26]	0.25
	Day 2	1	19 (–)	14	24 [20–29]	–
	Day 3	1	15 (–)	13	25 [21–29]	–
	Maximum during stay	3	20 [20–23]	24	27 [22–33]	0.05*

Values are presented in number (%) or median [interquartile range, IQR]

FiO₂ fraction of inspired oxygen, PEEP positive end-expiratory pressure, PvCO₂ venous partial pressure of carbon dioxide, TBI traumatic brain injury

**p* value < 0.05

difficult. This may also explain why clinically significant differences were not detected in the two groups. Due to the low prevalence of chest trauma in pediatrics, it is, therefore, very difficult to include a large and homogeneous cohort of patients. However, despite those limitations, we consider that our study provides some innovative and relevant data regarding the management of chest trauma in the pediatric population.

Conclusion

Mechanical ventilation to manage the most severe patients with TBI in the presence of thoracic injury does not seem to be associated with more acute respiratory distress syndrome occurrence in this single-center and retrospective study. It remains unclear which ventilation strategy should be promoted in this population. Future prospective studies are warranted to study the impact of mechanical ventilation practice outcomes in these patients presenting both thoracic and brain injury following trauma.

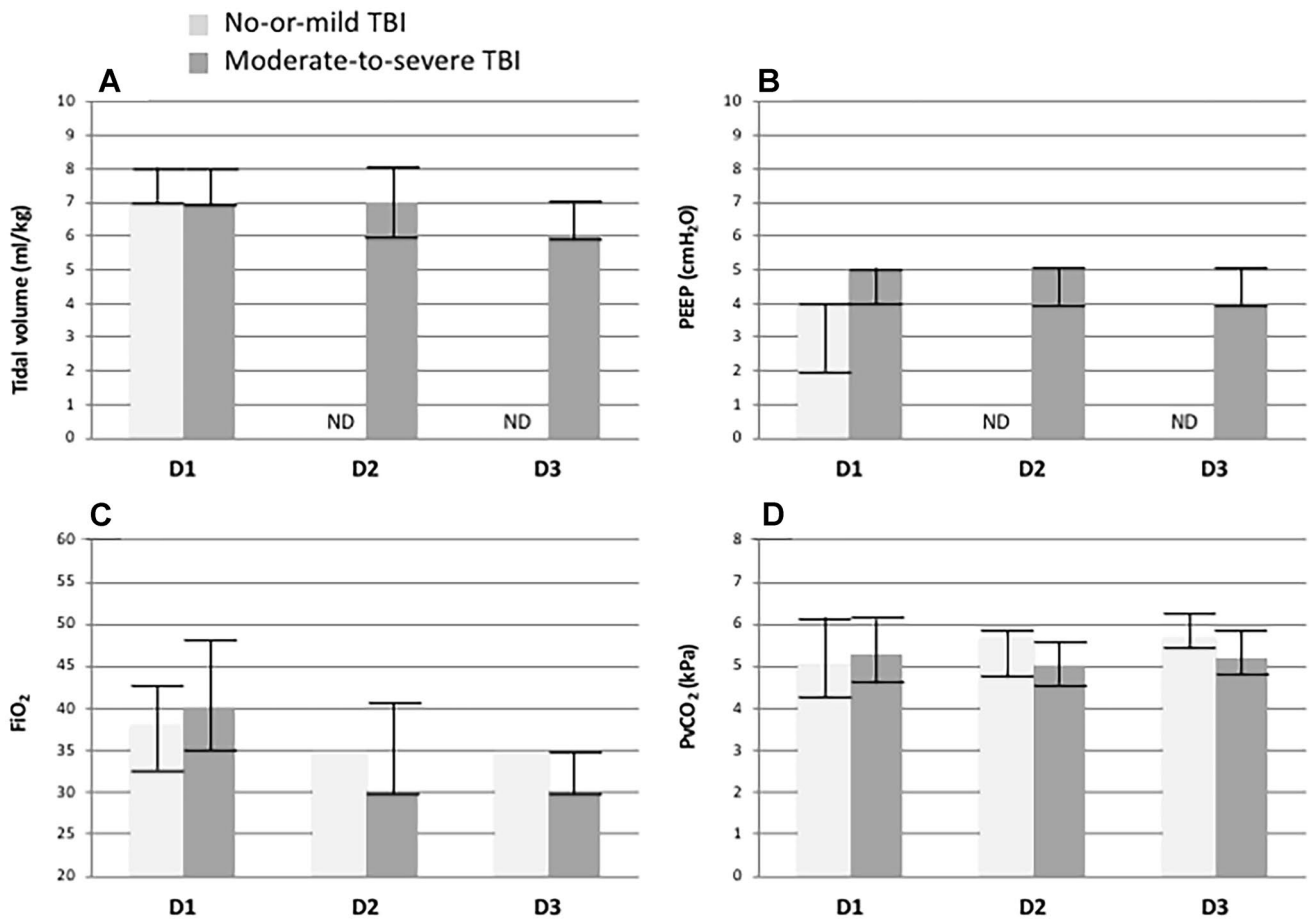


Fig. 2 Patterns of mechanical ventilation according to the association with (dark grey bars) or without (light grey bars) moderate-to-severe TBI. **A** tidal volume, **B** positive end-expiratory pressure (PEEP),

C FiO₂ and **D** venous partial pressure of carbon dioxide (PvCO₂). Median values and interquartile ranges are presented. ND: no data available

Author contributions CB and CI analyzed the data; CB, JNE and BC wrote the manuscript, which was reviewed, edited, and approved by PB and GM.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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